Carbon Emissions Management of the Petrochemical Industries in Thailand

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ABSTRACT

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Nitida Nakapreecha

Petrochemical industry is one of the major industries in Thailand. Although the petrochemical industry is aware of its environmental responsibility and environmental management and controls have been implemented; the industry was motivated to advance their environmental performance in order to be able to tackle: the issue of global climate change, the rising local concern over environmental impact; the new forms of trading barrier; and the national goal towards sustainable growth.

This study developed a carbon budget for Thai petrochemical industries, which covered 52 products from upstream, intermediate and downstream petrochemical industries together with plastics and derivatives industries. The study, it evaluated the need for carbon emissions reduction, assessed the possible emissions reduction and identified areas for carbon emissions mitigation.

The developed carbon budget of Thai petrochemical industries for the year 2008 was 11 Mtonnes CO_2eq (±10%) and the emission intensity was 0.63 ktonnes CO_2eq per ktonne of production (±10%). It was found that Thai petrochemical industries had relatively low carbon emissions in comparison to other Thai industries and to chemical industries of other countries. Despite this result and the fact that there was currently no carbon emissions reduction obligation for Thai industries, it was suggested that the petrochemical industries should still advance their environmental performance and technologies, which would help in preparing themselves for the potential future reduction obligations. It would also lead to less environmental management expenditure better green competitiveness, sustainable development of the industries and a better living standard for the country.

Accordingly, it was estimated that carbon emissions of Thai petrochemical industries could be reduced by 25-61% through adapting current best practice and the mitigation action should be started with enhancing energy efficiency at onsite utility plants. This result implies that Thai petrochemical industries did not need to resort to difficult or extraordinary solutions to make a substantial emissions reduction. Rather, what is needed is a good investment in existing effective technologies, engineering and environmental management. Other mitigation areas are development of less- or zero- carbon intensive material and energy, development of cleaner technologies, and carbon capture and storage.

CARBON EMISSIONS MANAGEMENT OF

THE PETROCHEMICAL INDUSTRIES IN THAILAND

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NOMENCLATURE

3Rs	Reduce, Reuse, and Recycle
AAUs	Assigned Amount Units
ABS	Acrylonitrile Butadiene Styrene
AD	Activity Data
ASR	Age-Standardised Incident Rate
BCA	Border Carbon Adjustments
BF	Boiler Efficiency
BMA	Butyl Methacrylate
BOD	Biochemical Oxygen Demand
BOT	Bank of Thailand
BR	Polybutadiene Rubber
Cal	Calorie
CCC	Committee on Climate Change
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
COD	Chemical Oxygen Demand
CSR	Corporate Social Responsibility

DE	Germany
DEDE	Department of Alternative Energy Development and Efficiency
DEFRA	Department for Environment Food and Rural Affairs
DEG	Di-Ethylene Glycol
DOP	Dioctyl Phthalate
E&P	Exploration and Production
EACI	Executive Agency for Competitiveness and Innovation of the European Commission
EB	Ethyl Benzene
EDC	Ethylene Dichloride
EERE	Office of Energy Efficiency and Renewable Energy
EF	Emission Factor
EG	Ethylene Glycol
EGAT	Electricity Generating Authority of Thailand
EIA	Environmental Impact Assessment
EIT	Economies In Transition
EO	Ethylene Oxide
EPDM	Ethylene Propylene Diene Elastomer Rubber
EPS	Expanded Polystyrene
EU	European Union
FOE	Friend of the Earth
FR	France
g	Gramme
GBP	British Pound Sterling

gCO_2eq	Gramme of Carbon Dioxide Equivalent
GDP	Gross Domestic Product
GOT	Government of Thailand
GPP	Gross Provincial Product
GWP	Global Warming Potential
H_2O	Hydrogen Oxide (or water)
HDPE	High Density Polyethylene
Hg	Mercury
HIA	Health Impact Assessment
IEAT	Industrial Estate Authority of Thailand
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
JP	Japan
kg	Kilogramme
km	Kilometre
ktoe	Kilotonne of Oil Equivalent
$ktonnes_{production}$	Ktonne of Production
kWh	Kilowatt-hour
l	Litre
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
LPG	Liquefied Petroleum Gas
MCF	Methane Correction Factor
MEG	Mono-Ethylene Glycol

Mil. GBP	Million British Pound Sterling
Mil. THB	Million Thai Bath
MJ	Megajoule
MMA	Methyl Methacrylate
MOEN	Ministry of Energy
MSTE	Ministry of Science, Technology, and Environment
MTBE	Methyl Tertiary Butyl Ether
Mtonne	Million Tonnes
MTPIE	Map Ta Phut Industrial Estate
MW	Megawatt
N_2O	Nitrous Oxide
NA	Not Available
NESDB	Office of the National Economic and Social Development Board
NMVOC	Non-Methane Volatile Organic Compound
NO_x	Oxides of Nitrogen
NZ	New Zealand
OECD	Organisation for Economic Co-operation and Development
OTC	Over-the-Counter
PA	Phthalic Anhydride
Pb	Lead
PC	Polycarbonate
PCD	Pollution Control Department
PEG	Polyethylene Glycol
PET	Polyethylene Terephthalate

PM10	Particulate Matter up to 10 micrometers in size
PP	Polypropylene
ppb	Part Per Billion
ppmv	Part Per Million by Volume
PS	Polystyrene
PST	Parliamentary Office of Science and Technology
PTA	Purified Terephthalic Acid
PTIT	Petroleum Institute of Thailand
PU	Polyurethane
PVAc	Polyvinyl Acetate
PVC	Polyvinyl Chloride
R&D	Research and Development
SAN	Styrene Acrylonitrile
SBR	Styrene Butadiene Rubber
SF_6	Sulphur Hexafluoride
SM	Styrene Monomer
SO_2	Sulphur Dioxide
SO_x	Oxides of Sulphur
SPP	Small Power Producers
TEG	Tri-Ethylene Glycol
TGO	Thailand Greenhouse Gas Management Organisation
THB	Thai Bath
TSP	Total Suspended Particulates
UK	United Kingdom

UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USEPA	United States Environmental Protection Agency
VCM	Vinyl Chloride Monomer
VCR	Vinyl Cis polybutadiene Rubber
VOC	Volatile Organic Compounds
y	Year
µg	Microgramme

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CHAPTER 1

INTRODUCTION

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1.1 PROJECT BACKGROUND

This study was motivated by 4 main issues: global climate change, rising local concern over environmental impact, new forms of trading barrier, and national goal towards sustainable growth.

1.1.1 Global climate change

1.1.1.1 Climate change at the World scale

Climate change has long been a subject of intense public and political debate. Many studies substantiated that human-induced climate change was caused by the emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs) that have been accumulated in the atmosphere over the past 100 years (Stern, 2008). Activities involving the increases of the atmospheric concentration of these GHGs included burning of fossil fuel, agriculture and land-use change.

The first clear evidence of an atmospheric CO_2 increase was obtained from data collected in Antarctica and at Mauna Loa from 1957 and 1958 respectively (Fraser, et al., 1986). A back extrapolation of the Mauna Loa record, assuming a constant airborne fraction of the estimated fossil fuel input, yielded a calculated "preindustrial" value of approximately 295 part per million by volume (ppmv) (Fraser, et al., 1986). Stern (2008) reported that emissions rose at an average annual rate of over 3% between 1950 and 2002. In 2000, the stocks of GHGs in the atmosphere were at 430 ppmv carbon dioxide equivalent (CO_2eq) and was rising at roughly 2.5 ppmv every year. It was forecasted that if the emissions continued unabated, they would reach 550 ppmv CO_2eq by 2035 and would be over 700 ppmv CO_2eq by the end of the century (Stern, 2008). As GHGs have a property that traps heat, the higher the atmospheric GHG concentration, the higher average global temperature would be. The risks of the worst climate change impacts could be substantially reduced if the atmospheric GHG levels could be stabilised between 450–550 ppmv

CO_2eq. The stabilisation at 450 ppmv CO_2eq would lead to an around 5-20% change of global mean temperature ultimately exceeding 3^oC above pre-industrial and stabilisation at 550 ppmv CO_2eq would lead to about 30-70% chance of exceeding 3^oC rises. The chance would reach about 60-95% for stabilisation at 650 ppmv CO_2eq (Stern, 2008). This temperature increase may look small but small changes in global-average surface temperature correspond to large changes in climate patterns that greatly influence human activities and the entire ecosystems (Schneider, et al., 2010). The effect starts from the basic elements such as fresh water scarcity, poor food production, more severe disease and loss of biodiversity; to major catastrophes such as floods, droughts, heat waves, and wildfires. The disruption also drives the increase in the power of hurricanes and typhoons. Additionally, the World Health Organisation estimated in 2002 that global climate change was responsible for 150,000 premature deaths worldwide already in 2000. The number would be higher today (Schneider, et al., 2010).

All countries would be affected even though they had different contribution to the causes of climate change. However, they would be affected in different ways and to different extents. Developing countries would be terribly affected because of their geographic exposure, low incomes, and greater reliance on climate dependent sectors such as agriculture (Stern, 2008).

To reduce the risk of damaging impacts from climate change requires strong actions from all countries. The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol provided a basis for international cooperation. The UNFCCC, in 1992, laid the framework for stabilisation of greenhouse gases (GHGs) in the atmosphere at a level that would prevent dangerous anthropogenic interference with climate system; whereas the Kyoto Protocol, in 1997, laid out guidelines and rules regarding the extent to which each industrialised country should reduce its emissions of six specified GHGs. The Kyoto Protocol required industrialised countries, so-called Annex I parties, to reduce their GHGs by an average of 5% against 1990 levels over the five-year period 2008-2012 (UNFCCC, 2010). However, it did not mandate developing countries to reduce their emissions. Box 1.1 provides details about parties under Kyoto Protocol.

Box 1.1

Parties under Kyoto Protocol

Countries were divided into 3 main groups under the Kyoto Protocol according to their differing commitments:

Annex I Parties include the industrialised countries that were members of the Organisation for Economic Co-operation and Development (OECD) in 1992, plus countries with economies in transition (EIT), including the Russian Federation, the Baltic States, and several Central and Eastern European States.

Annex II Parties consist of the OECD members of Annex I, but not the EIT Parties. They are required to provide financial resources to enable developing countries to undertake emissions reduction activities under the Convention and to help them adapt to adverse effects of climate change. In addition, they have to take all practicable steps to promote the development and transfer of environmentally friendly technologies to EIT Parties and developing countries. Funding provided by Annex II Parties is channelled mostly through the Convention's financial mechanism.

Non-Annex I Parties are mostly developing countries. Certain groups of developing countries are recognised by the Convention as being especially vulnerable to the adverse impacts of climate change, including countries with low-lying coastal areas and those prone to desertification and drought. Others (such as countries that rely heavily on income from fossil fuel production and commerce) feel more vulnerable to the potential economic impacts of climate change response measures. The Convention emphasises activities that promise to answer the special needs and concerns of these vulnerable countries, such as investment, insurance and technology transfer.

Source: UNFCCC, 2010

There were 3 main mechanisms under Kyoto Protocol to help stimulate environmental friendly investment and help Parties meet their emissions reduction targets in a cost effective way.

- *Emissions trading*

  Parties with commitments under the Protocol could emit their emissions at the allowed level called assigned amount units (AAUs). Emissions trading allows countries that have spare units and do not use them to sell these quotas to other countries that cannot meet their targets. Because carbon dioxide is the main greenhouse gas, people simply use the term “carbon trading”. Accordingly, carbon becomes a new commodity which can be tracked and traded like any other commodity. This is known as the carbon market (UNFCCC, 2010).

- *Clean development mechanism (CDM)*

  The clean development mechanism (CDM) allows a country with a commitment under the Kyoto Protocol to implement an emissions reduction project in developing countries. Such projects could earn saleable certified emissions reduction (CER) credits, each equivalent to one tonne of CO_2, which could be counted towards meeting Kyoto targets (UNFCCC, 2010).

- *Joint implementation (JI)*

  Joint implementation (JI) allows an Annex I country to invest in emissions reduction or emission removal project in another Annex I country and earn emissions reduction units (ERUs) from such projects. The ERUs earned could be counted towards meeting the Kyoto target (UNFCCC, 2010).

Besides emissions mitigation, every country needed to prepare appropriate adaptation measures to minimise danger from climate change, for example, developing heat- and drought- resistant crops, advancing medical treatments for more severe diseases, building more dams to contain floods and dykes to cope with rising sea level.

1.1.1.2 Thailand and its role on climate change mitigation

Thailand’s GHG emissions have been steadily increasing, placing Thailand among the top 25 GHG emitting countries. Between 1994 and 2003 Thailand’s GHG emissions grew from 286 million tonnes of carbon dioxide equivalent (Mtonne of CO_2eq) to 344 Mtonne of CO_2eq - an annual rate of about 2% (Government of Thailand (GOT), 2009). Continued economic expansion, a growing population, and increased dependence on more carbon-intensive fossil fuels suggested that Thai GHG emissions would continue to grow at this 2% rate if not even faster. Particularly, GHG emissions growth from fossil fuel source has been growing at 3% per annum, mostly in the form of petroleum products (Figure 1.1). According to the latest data from the Energy Information Administration, US Department of Energy, energy-related GHG emissions of

272 Mtonne of CO_2eq in 2006 placed Thailand as 24th among the World's largest GHG emitters (GOT, 2009).

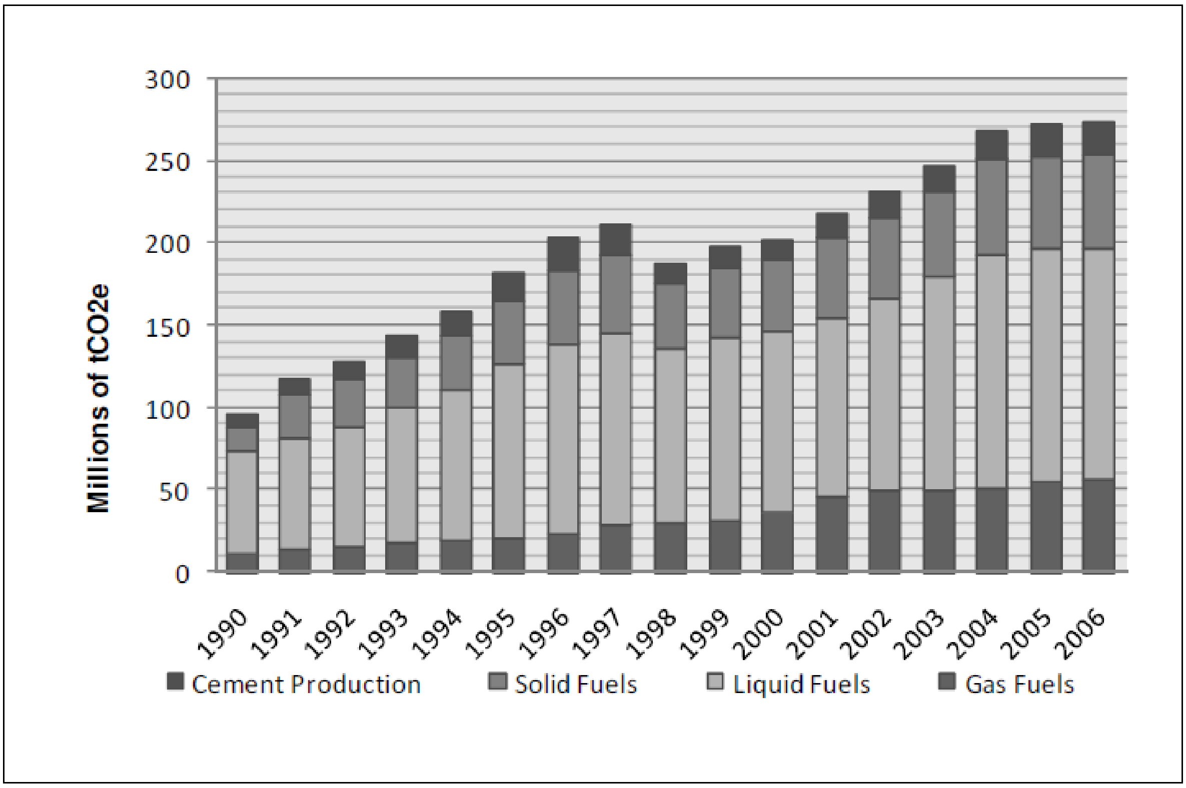


Figure 1.1 Thailand's CO_2 emissions from fossil fuels (GOT, 2009)

The largest contributors to Thailand's GHG emissions were the electricity generation and transport sectors. In 2006 more than a third (37%) of GHG emissions stemmed from electricity sector. The second largest GHG emissions contributor was transport sector (26%), with manufacturing sector accounted for almost another quarter (23%) of emissions, followed by residential and commercial sectors – Table 1.1.

<u>Table 1.1</u> Thailand's greenhouse gas emissions by sector

Sector	2002	2006
Transport	29.29%	26.32%
Electricity	38.69%	37.45%
Manufacturing	22.65%	22.96%
Residential and commercial	3.36%	7.75%
Others	6.01%	5.53%
Total	100%	100

Source: GOT, 2009.

As a non-Annex I country, Thailand was not mandated to limit or reduce its GHG emissions under the Kyoto protocol. But over the longer term, as the convention and the protocol process unfolds, there was a concern that developing countries might be pressured into accepting limits on their future GHG emissions. With the concern over the GHG emissions status together with the concern of possible obligations, the government put in the strategy in response to the UNFCCC and Kyoto Protocol as follow:

- *Follow the movements of the UNFCCC and the Kyoto Protocol and their discussion issues.*
- *Set up a team of specialists to be ready for negotiations.*
- *Identify clear regulation about types of projects that should be performed as well as distribute benefits from carbon credit trading under clean development mechanism.*
- *Promote international cooperation at global, regional, multi-lateral and bilateral levels.*
- *Exchange experience.*
- *Build networks of learning in order to negotiate and protect national interests.*

As of 2009, Thailand had voluntarily reduced its GHG emissions through CDM implementation. Twenty four projects were registered at the UNFCCC Executive Board with an estimated total emissions reduction of 1.7 Mtonne of CO_2eq (GOT, 2009). In addition, Thailand planned to cut its GHG emissions by 15-20% (equal to 1 million tonne per year) from power sector and refineries through CDM (Pollution Control Department (PCD) of Thailand, 2008). However, a firm timeline for implementation was still missing.

1.1.2 Rising local concern over environmental impact

Local environmental problems had long been an issue in Thai society but the concern intensely increased just in the last decade. This might be because of the emerging industrial incidents, the increase in people's environmental consciousness, the intense interest in global climate change issue and more variety of communication channels. Industries, particularly the large one e.g. oil refineries and petrochemical industries, were blamed as a big source of pollution. These industries were under pressure to improve their environmental performance in order to gain social acceptance and recover their good image. However, the latest social movement against industrial activities resulted in the halt of the expansion of the petrochemical industries costing considerable financial damage. This might be the perfect time for all concerned parties, not just the industries to start taking care of the environment seriously.

1.1.3 New forms of trading barrier

Many countries, especially those listed as Annex I countries, have been attempting to reduce their carbon emissions in every possible way. One approach was through selecting imported goods with low carbon footprint. Box 1.2 provides a definition of carbon footprint.

Box 1.2

Definition of carbon footprint

Carbon footprint is the total amount of greenhouse gas emissions caused by an organisation, event, product or person (Carbon Trust, 2009). It is usually expressed in the unit of the carbon dioxide equivalent (CO_2eq).

Moreover, the European Union (EU) planned to issue a new tax system called border carbon adjustment. Border carbon adjustments (BCA), also known as border tax adjustments or border tax assessments, are import taxes levied by carbon-taxing countries on goods manufactured in non-carbon-taxing countries (Carbon Tax Center, 2009). Its objective is to ensure a fair level playing field in international trade while internalising the costs of climate damage into prices of goods and services. It also indirectly prevents carbon leakage (Box 1.3). As the EU were binding to emissions reduction requirements, there was concern over their competitiveness against countries with no legally emissions reduction binding or with less environmental strictness. Some heavy emitting EU industries responded to this issue by relocating their factories in countries with lower environmental requirements

If the EU were to use BCA, it would mean that imports from other countries including Thailand might be subjected to environmental requirements in order to access EU markets. Nevertheless, the European Commission stated that the measures would be in conformity with the principles of the UNFCCC, taking into account the principle of common but differentiated responsibilities and respective capabilities with respect to developing countries (Thailand Creenhouse Gas Manangement Organisation (TGO), 2010).

Box 1.3

Definition of carbon leakage

Carbon leakage is defined as an increase in emissions in the regulated area as a direct result of the policy to cap emissions in that area (Reinaud, 2008). For example, the entrepreneur might shift their investment from the strictly regulated industrial zone to the less or no strictly regulated zone, which in the matter of fact, do not reduce the total emissions but create the problem in the new area.

Therefore, besides the regular import tariff, Thailand needed to confront the new trading conditions both in the form of tariff and non-tariff controls: they could be viewed as trading barriers or challenges for better manufacturing. The conclusion was obvious: in order to preserve the global market share, Thailand must ensure that carbon footprint of their exported goods are at the acceptable and competitive level, otherwise, the future of their export might be at risk, resulting in an unacceptable impact upon the domestic supply chain.

1.1.4 National goal towards sustainable growth

There was a concern that people used resources extravagantly without awareness of their limitations or impacts. The expansion of the economic sector increased pollution and waste, which affected both environment and people's health (Office of the National Economic and Social Development Board (NESDB) of Thailand, 2007). Thailand needed to make strong actions in controlling emissions in order to minimise the adverse impact on natural and socio-economic systems.

The Tenth National Economic and Social Development Plan (2007-2011) stated that Thailand must upgrade its standards of environmental management in order to protect the resource base and maintain a sustainable balance in the national environment, by developing more efficient systems for administering and managing natural resources with a participatory process. It must also adjust processes of producing goods and services to become more environmental friendly, and must increase efficiency in energy usage and develop alternative energy sources to meet domestic demand for energy (NESDB, 2007). Accordingly, the government laid out a broad strategy emphasising 4 aspects as follow:

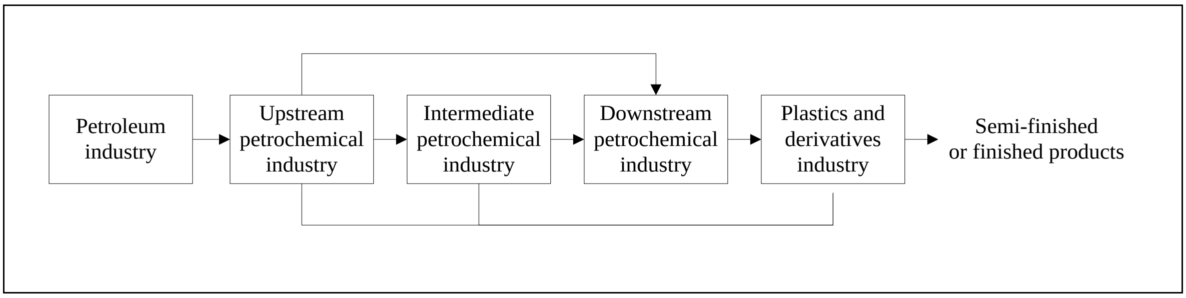
- Patterns of production and consumer behaviour would be modified for sustainability in order to reduce the impact on the natural resource base and environment.
- Public policy and economic mechanisms, both fiscal and monetary, will be used to create markets for environmental friendly goods and services.
- Pollution would be reduced and controls imposed on activities that have impact on the quality of life by instituting strategic environmental assessments, and health and social impact assessments in development government projects or those approved by government for private management.
- The capacity of local government bodies and communities to manage the environment would be improved.
- Mechanisms instituted to set the country's stance towards international obligations and agreements on the environment.

In summary, all factors described above indicated that the World was moving towards carbon-constrained economy in response to the global climate change concern. The increase of greenhouse gas emissions policies and public environmental awareness posed challenges to every sector around the globe. In order to thrive in this circumstance, Thailand needed to consider its carbon emissions profile and advance its emissions management. It was not just about the impact of products on the environment, but also the commitment to sustainable business practice up and down the value chain. This could start with an industrial sector, which was viewed as one of the major polluters.

1.2 THE PETROCHEMICAL INDUSTRIES IN THAILAND: THE DEVELOPMENT AND IMPORTANCE

1.2.1 What are petrochemicals?

Petrochemicals are hydrocarbons and compounds derived from petroleum, such as crude oil and natural gas, which are further processed into higher-valued products. Petrochemicals are best renowned for their versatility and substitution for national resources such as wood, metal and non-metal. In general, petrochemical value chain could be categorised into 3 stages: upstream petrochemical industry, intermediate petrochemical industry and downstream petrochemical industry. Subsequently, there is plastics and derivatives industry that uses petrochemical products to produce semi-finished or finished goods used in daily lives such as plastic bottles, films, pipes, etc. The term of "petrochemical industries" used in this study refers the upstream, intermediate and downstream petrochemical industries together with the plastics and derivatives industry. Figure 1.2 shows simple flow diagram of the petrochemical industries.



<u>Figure 1.2</u> Simple flow diagram of petrochemical value chain

1.2.1.1 Upstream petrochemical industry

Upstream petrochemical industry is an industry that uses petroleum products to produce petrochemical products namely olefins and aromatics, which are further used as raw materials for derivative petrochemical production (Petroleum Institute of Thailand (PTIT), 2010). The upstream petrochemical industry has 7 products which are very important to the development of the entire petrochemical value chain. These products could be grouped based on their molecular structure as follow.

1.2.1.1.A) Alkane group

Main product of the alkane group is methane, which is a precursor of synthesis gas. It is also used in the production of methyl alcohol and ammonia. Methyl alcohol is used in the production of oxo-alcohol, ethyl alcohol, acetic acid and formic acid. Ammonia is used in the production of chemical fertiliser.

1.2.1.1.B) Olefins group

Olefins group consists of 3 products.

i) Ethylene, which is used in the production of plastic resins such as low density polyethylene (LDPE), linear low density polyethylene (LLDPE), high density polyethylene (HDPE), poly vinyl chloride (PVC) and other chemicals i.e. acetic acid

ii) Propylene, which is used in the production of plastic resins such as polypropylene (PP), and nylon 6,6. It is also used in the production of other chemicals i.e. butyl alcohol, 2 ethyl hexanol, cumene and acrylonitrile.

iii) Mixed C4, which is a precursor for octane booster or methyl tertiary butyl ether (MTBE). It is also used in the production of plastic resins e.g. acrylonitrile butadiene styrene (ABS); and synthetic rubbers e.g. polybutadiene rubber (BR), styrene butadiene rubber (SBR).

1.2.1.1.C) Aromatics group

Aromatics group consists of 3 products.

i) Benzene, which is used in the production of plastic resins such as polystyrene (PS), polycarbonate (PC); synthetic rubbers e.g. styrene butadiene rubber (SBR), styrene acrylonitrile (SAN); and other chemicals e.g. phenol.

ii) Toluene, which is further processed into higher value aromatics products such as p-xylene and benzene. Toluene is also used in the production of polyurethane (PU) and solvent.

iii) Xylene, which comprises of mixed-xylene, para-xylene or p-xylene, ortho-xylene or o-xylene and meta-xylene or m-xylene. Mixed-xylene is used as solvent and can be further processed into other xylenes (p-,o-, and m-xylene). P-xylene is used in the production of polyethylene terephthalate (PET) and polyester. O-xylene is used in the production of PVC plasticizer. And m-xylene is used to make solvent.

1.2.1.2 Intermediate petrochemical industry

Intermediate petrochemical industry is an industry that uses petrochemicals produced by the upstream industry to produce petrochemical products that are further used as raw materials by downstream industry (PTIT, 2010). Examples of intermediates are as follow:

1.2.1.2.A) *Alkane intermediates:* methanol or methyl alcohol, formaldehyde, and ammonia.

1.2.1.2.B) *Olefins intermediates:* ethylene dichloride (EDC), vinyl chloride monomer (VCM), ethyl oxide (EO), and ethylene glycol (EG).

1.2.1.2.C) *Aromatics intermediates:* ethyl benzene (EB), styrene monomer (SM), cyclohexane, caprolactum, and purified terephthalic acid (PTA).

1.2.1.3 Downstream petrochemical industry

Downstream petrochemical industry is an industry that uses petrochemicals produced by the upstream industry and/or intermediate industry to produce petrochemical products that are further processed by the processing industry through transformation into semi-finished and/or finished goods (PTIT, 2010). The downstream petrochemical industry could be classified based on their functions as follow:

1.2.1.3.A) *Plastic resins*

i) Commodity plastics are easily transformed. Their mechanical properties such as durability and strength are not as high as those of engineering or high performance plastics. Examples of commodity plastics are low density polyethylene (LDPE), linear low density polyethylene (LLDPE), high density polyethylene (HDPE), poly vinyl chloride (PVC), polypropylene (PP), and polystyrene (PS). Commodity plastics are used in high volume and a wide range of applications, such as packaging bags, films, and plastic bottles.

ii) Engineering plastics can substitute metal in engineering works. For example, they can be used in the production of automobile parts and computer parts.

Examples of engineering plastics are polycarbonate (PC), polyacetal, acrylonitrile butadiene styrene (ABS) and poly ethylene terephthalate (PET)

iii) High performance plastics are plastic materials that have superior mechanical and thermal properties for specialty work. These plastics are often of high cost. Example of high performance plastics are polytetrafluoroehylene or teflon, poly ether ether ketone (PEEK), and polyethersulfone (PES). Currently, these plastics are not widely used nor produced in Thailand as they require high technology in the production process.

1.2.1.3.B) Synthetic fibres

Synthetic fibres are alternatives for the textile industry. Properties of synthetic fibres can be freely adjusted to suit various demands. Technology can make synthetic fibres identical to or completely different from natural fibres. Synthetic fibres can be used solely or combined with other fibres for diverse applications.

1.2.1.3.C) Synthetic rubbers and elastomers

Synthetic rubbers are invented with elasticity of natural rubbers but have better durability. Thus, they can be greatly substituted for natural rubbers in the automobile industry. Examples of synthetic rubbers are polybutadiene rubber (BR), styrene butadiene (SBR), butyl rubber, nitrile rubber, ethylene propylene diene elastomer rubbers (EPDM)

1.2.1.3.D) Synthetic coating and adhesive materials

Examples of synthetic coating are polyurethanes (PU), and epoxy resins. Examples of adhesive materials are phenol formaldehyde and poly vinyl acetate (PVAc).

1.2.1.4 <u>Plastics and derivatives industry</u>

Plastics and derivatives industry is the industry that uses petrochemicals produced by any segment of the upstream, intermediate or downstream petrochemical industries to produce semi-finished and/or finished goods through simple transformation.

1.2.2 The development of the petrochemical industries in Thailand

Thailand began importing plastic products after World War II. At that time, availability was limited to finished products such as hair clips, belts and combs, which were of high price. By the mid of 1950s, a local factory was developed and used imported plastic resins (Ratanarat, et al., 2003). After that, downstream factors producing poly vinyl chloride (PVC) and expanded polystyrene (EPS) were operated for domestic supply and import substitution (PTIT, 2010). But the pioneer was not exactly a phenomenon. In the late 1970s, the discovery of natural gas in the Gulf of Thailand greatly provided a future for the country both in terms of energy security and economic growth. Its composition made it suitable for a source of energy and a raw material (Figure 1.3). The government, therefore, set out an economic system and industrialisation plan, so-called the Eastern Seaboard Development Plan (1980-1989) to maximise the benefits of the indigenous natural gas. The plan involved establishment of gas separation plant to separate out fractions that could be further processed into more valuable products; and establishment of petrochemical industrial complex at Map Ta Phut industrial zone, where infrastructures and utilities could be fully developed.

The development of the first petrochemical complex had only upstream petrochemical plants. There were one ethane-based ethylene cracker with propane dehydrogenation unit, two polyethylene plants, one polypropylene plant and an ethylene dichloride/vinyl chloride monomer/polyvinyl chloride (EDC/VCM/PVC) complex. The capacities were based on meeting domestic demand. Table 1.2 shows designed capacities of the first phase development.

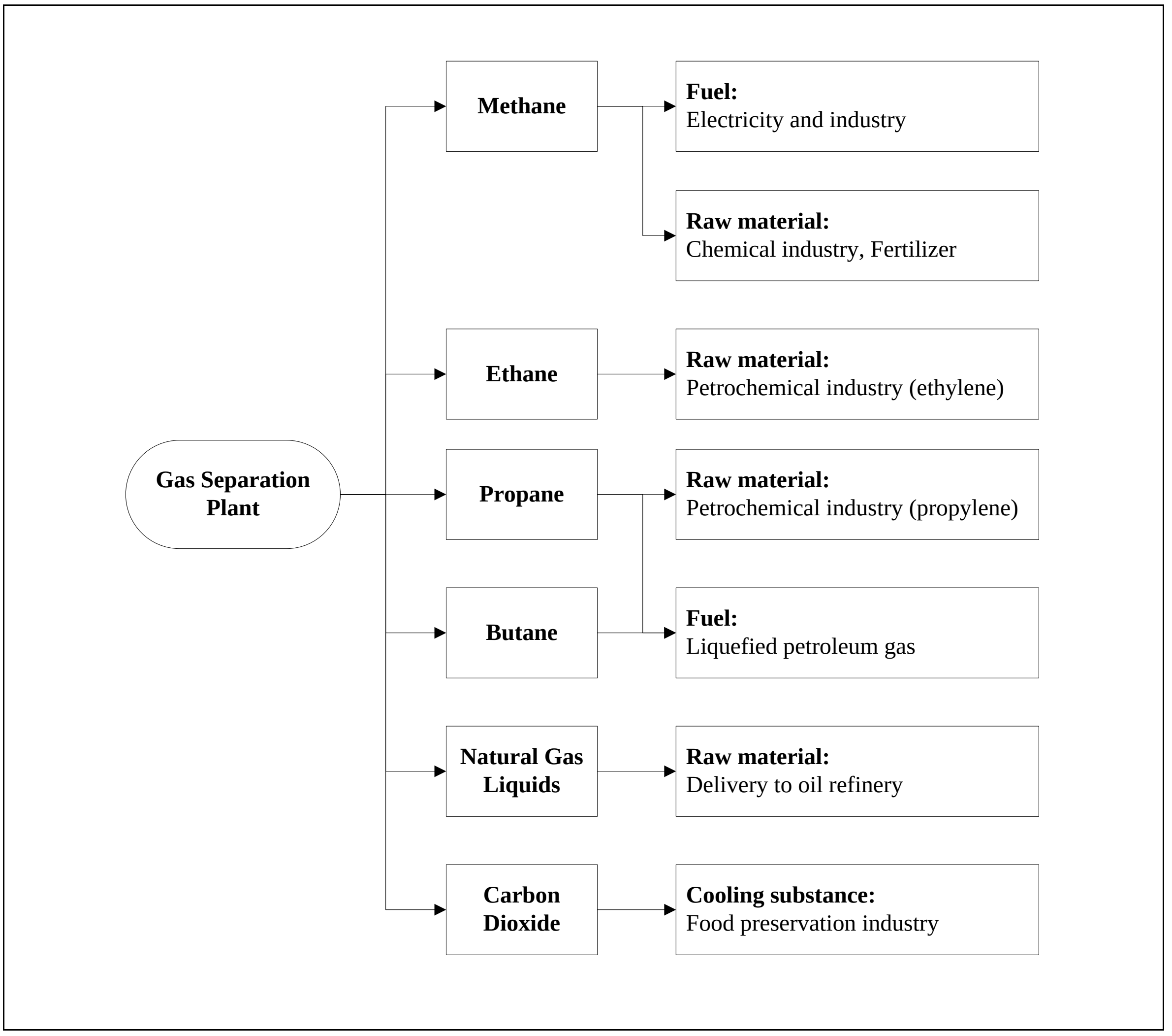


Figure 1.3 Simple natural gas separation streams and their usages

Table 1.2 Designed capacities of the first phase petrochemical industry development

Product	Capacity (tonne per year)
Upstream	
Ethylene	300,000
Propylene	73,000
Downstream	
Polypropylene (PP)	70,000
High density polyethylene (HDPE)	110,000
Low density polyethylene (LDPE)	100,000
Vinyl chloride monomer (VCM)	80,000
Ethylene glycol (EG)	50,000

In term of energy supply, the discovered natural gas has made a substantial reduction in oil imports for power generation. The Electricity Authority of Thailand (EGAT) reported a decline in their oil consumption from 77.3% in 1980 to 21.0% by 1998 after the introduction of natural gas in their overall energy consumption (Ratanarat, et al., 2003).

The second master plan (1989-2004) of for petrochemical industry development was published in 1987 (Ratanarat, et al., 2003). This second phase of the development aimed to broaden a range of products, particularly on the aromatics-based chains such as polyester, nylon, polystyrene, linear alkyl benzene, various solvents and synthetic rubbers. In addition, the intermediate industry at the time was still at an early stage of its development and required considerable investment. Stimulating downstream industry help pushed the demand for intermediate products and thus provided a basis for new investment. Furthermore, the plan also strengthened the capacity of the industries to enhance the competitiveness in the international markets. Table 1.3-1.5 show the designed capacities according to the second master plan.

Table 1.3 Upstream petrochemicals in the second master plan (based on demand projections for 1996) (unit: tonne per year)

Product	Demand	First Phase Capacity	Second Phase Capacity
Ethylene	595,000	315,000	280,000
Propylene	268,000	105,000	163,000
Benzene	116,000	-	116,000
Toluene	52,000	-	52,000
P-xylene	138,000	-	138,000
O-xylene	28,500	-	28,500
Mixed-xylene	15,500	-	15,500

Source: Ratanarat, et al., 2003.

Table 1.4 Intermediate petrochemicals in the second master plan (based on demand projections for 1996) (unit: tonne per year)

Product	Demand	First Phase Capacity	Second Phase Capacity
Vinyl chloride monomer	280,000	140,000	140,000
Styrene monomer	135,000	-	135,000
Linear alkylbenzene	30,000	-	30,000
Ethylene glycol	90,000	-	90,000
Purified terephthalic acid	205,000	-	205,000
Phthalic anhydride	30,000	27,000	3,000

Source: Ratanarat, et al., 2003.

Table 1.5 Downstream petrochemicals in the second master plan (based on demand projections for 1996) (unit: tonne per year)

Product	Demand	First Phase Capacity	Export Plan	Second Phase Capacity
Polyethylene	327,500	262,500	20,000	85,000
Polyvinylchloride	240,000	140,000	30,000	130,000
Polypropylene	220,000	100,000	35,000	155,000
Polystyrene	95,000	55,000	15,000	55,000
Polyester	240,000	240,000	-	-
Styrene acrylonitrile/ Acrylonitrile butadiene styrene	28,000	22,000	2,000	8,000
Styrene butadiene rubber/ Polybutadiene rubber	10,000	-	3,000	13,000

Source: Ratanarat, et al., 2003.

Naphtha became an important feedstock in the second phase development. Heavy naphtha had molecular structure that was appropriate for aromatics production while light naphtha made itself an alternative feedstock for olefins production. Both heavy naphtha and light naphtha could be acquired from domestic condensate. Light naphtha could also be acquired from local refineries and be imported.

The development of this second phase was still located at Map Ta Phut Industrial Estate due to its availability of infrastructure and utility system - this included roads, transportation systems, deep sea terminal, depots, communication systems, and environmental monitoring and control systems. More importantly, developing as a cluster would increase operational efficiency and decrease transportation costs at the same time, which directly fostered the competitiveness of the industries in the international markets.

The latest government plan (2004-2018) for the third wave of petrochemical industry development aimed at competitiveness, integration, clusters and alliances as tools to support domestic industrial growth and advance towards more sophisticated and higher value-added products. However, this required such technology that was not readily-available and which might need to be acquired through joint ventures with companies that had the technological capacity. It was important for Thailand to carefully assess its attractiveness for foreign investment, including: sufficiency of supporting infrastructure; feedstock competitiveness; adequate domestic consumption; utility cost; financial services; national economy; and appropriate regulations.

1.2.3 The importance of the petrochemical industries in Thailand

Thai petrochemical industries expanded rapidly, both in capacity and complexity. Multi-billion Baht investments from both domestic and foreign investors were invested in the industries and the industries expanded to the extent that plastic goods had replaced many of the articles traditionally used by Thais, such as banana leaves (to wrap things in or folded into bowls), wooden bowls, wooden crates, and zinc dishes (Ratanarat, et al., 2003). The industries were ones of the key sectors driving the national economy. They contributed approximately 5-7% of the national gross domestic product (GDP) (PTIT, 2010). Their contributions to the total export increased every year and were at 4.85% in 2005 (Box 1.4). In addition, petrochemical industries were important elements for many other industries leading to a greater economic multiplicity. The petrochemical industries also created numerous employment opportunities (PTIT, 2010).

Box 1.4

Thailand's total export value in 2002 – 2005

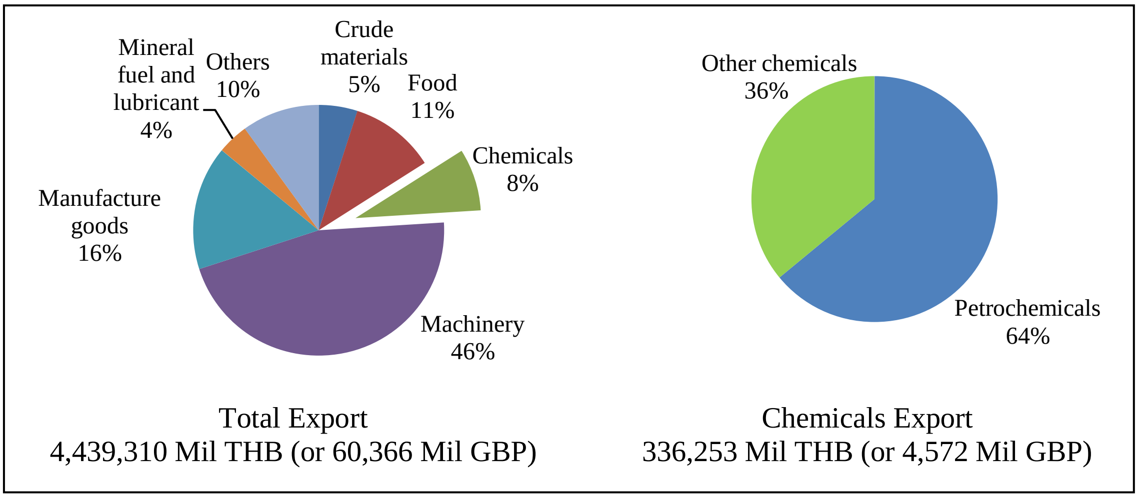


Figure 1.4 **Petrochemicals export in 2005**

Table 1.6 **Petrochemicals export comparing to total and automobile export**

Export[1]		**2002**	**2003**	**2004**	**2005**
Average currency exchange[2] (THB per GBP)		64.94	68.17	74.13	73.54
Thailand's total export	Mil.THB	2,923,941	3,325,630	3,874,310	4,439,310
	Mil.GBP	45,025	48,784	52,264	60,366
Petrochemicals export	Mil.THB	98,869	123,391	166,844	215,299
	Mil.GBP	1,522	1,810	2,251	2,928
	% of total export	3.38%	3.71%	4.31%	4.85%
Automobile export	Mil.THB	107,729	138,161	202,079	294,243
	Mil.GBP	1,659	2,027	2,726	4,001
	% of total export	3.68%	4.15%	5.22%	6.63%

[1]From PTIT, 2007.

[2]From BOT, 2011.

1.2.4 Petrochemical industries and environmental practices

The government issued a number of environmental laws and regulations to mandate any project or activity that had a potential environmental impact in order to conserve the environment. The laws and regulations that are relevant to the petrochemical industries are listed in Appendix C. Furthermore, before establishing a factory, an entrepreneur must complete an environmental impact assessment (EIA) to assess the impact of their operations on the quality of air, water, soil, noise level and living systems at the industrial site and surrounding area. Pollution mitigation plan must be provided for within the environmental impact assessment.

Although the health, safety and environment programmes undertaken by producers generally increased cost by up to 15% of their total investments, they were convinced that the investment pays off in the long run in ensuring customer acceptance and in enhancing competitiveness, especially in the international markets such as Europe, United States of America and Japan (Ratanarat, et al., 2003). So far, petrochemical companies operating in Thailand have been conscientious in selecting the best technologies, ensuring that they are environmentally friendly and keeping emissions within stipulating standards.

1.3 OVERVIEW OF THE STUDY

Considering the importance to the national economy and the urgency of the environmental performance declaration, this study focuses on the petrochemical industries by clarifying their actual carbon emissions and suggesting emissions mitigation opportunity so that the country could enjoy the benefits from the industries in the sustainable way.

1.3.1 Aim and objectives

1.3.1.1 Aim

The aim of the study is to establish guidelines for carbon emissions management for the petrochemical industries in Thailand.

1.3.1.2 Objectives

1) To develop carbon/GHG budget of the petrochemical industries in Thailand (Chapter 2).
2) To evaluate carbon/GHG emissions status of Thai petrochemical industries and compare these with carbon/GHG budget of other Thai industries and carbon/GHG budget of pertinent industries of other countries (Chapter 3).
3) To evaluate possible carbon/GHG emissions reduction (Chapter 4) and identify areas for carbon/GHG emissions mitigation (Chapter 5).
4) To consider a major environmental case study (Chapter 6).

1.3.2 Scope of the study

1.3.2.1 The development of the carbon budget

The development of carbon/GHG budget covers the production processes of the upstream petrochemical industry, intermediate petrochemical industry, downstream petrochemical industry, and plastic and derivatives industry (Figure 1.5). It excludes the construction or transportation phase due to the lack of suitable data. This study attempts to cover as many products as possible for the most complete budget.

In addition, it covers 6 main greenhouse gases specified under the Kyoto protocol namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and Sulphur hexafluoride (SF_6)

1.3.2.2 Identification of carbon/GHG emissions mitigation areas

This study provides a broad description of possible tools of carbon/GHG emissions mitigation. It does not predict the best technology or the cheapest approach to achieve emissions reduction due to the lack of relevant data.

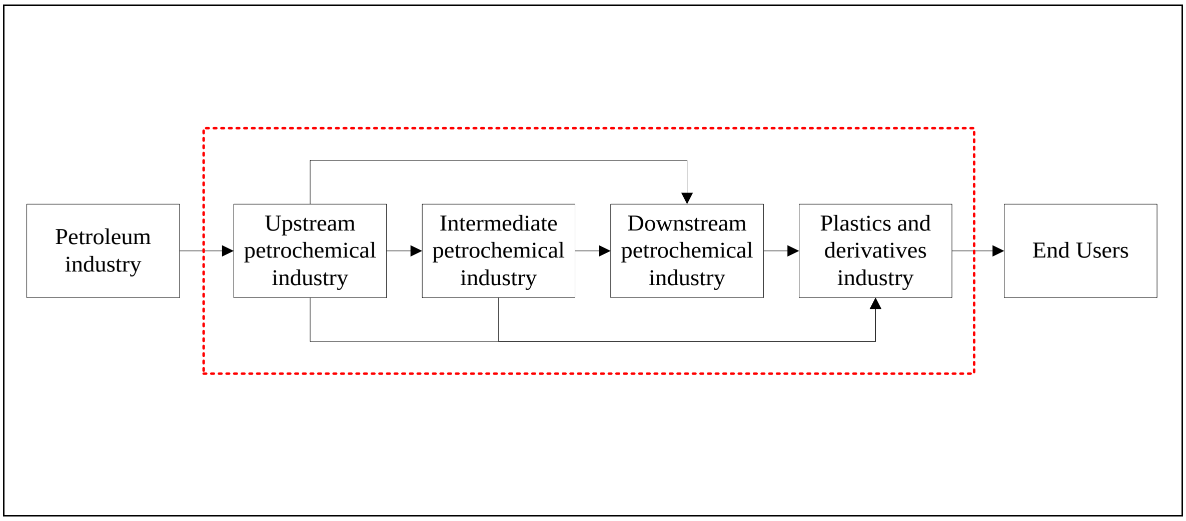


Figure 1.5 **Scope of the study**

1.3.3 Benefits of the study

It is expected that this study would provide benefits at national level, industrial level and community level as follow:

1.3.3.1 National level

- Preserve export markets especially those in countries with high-level of environmental concern such as Japan and countries in the European Union.
- Raise a green competitiveness, which also help expand export earning.
- Promote environmental friendly operations towards sustainable growth
- Encourage a decrease of the overall national greenhouse gas emissions, which would be beneficial for climate change negotiation at the global panel in the future.

1.3.3.2 Industrial level

- Promote the improvement of industrial operations leading to more efficient and cost effective operations.
- Benchmark Thai petrochemical plant relative to the entire petrochemical industries for competitive enhancement.
- Enhance a good image of environmental responsibility of the industries leading to a better social attitude towards the industries.

1.3.3.3 Community level

- Decrease local pollution resulting in less disturbance of nearby communities.

CHAPTER 2

CARBON BUDGET:

DEVELOPMENT METHODOLOGY

CHAPTER 2

CARBON BUDGET: DEVELOPMENT METHODOLOGY

2.1 INTRODUCTION

A carbon budget is a set amount of carbon that can be emitted in a given amount of time, either by the whole company, or a pre-selected sub-population or set of activities (Gilbert, et al., 2006). Thus, it can well represent the environmental effect a budget owner has and should be used as a starting point for an environmental management roadmap. In general, carbon budget refers to agreed or permitted emissions. However, as there was no limit of carbon emissions in Thailand, the term was applied in this study to represent actual or estimated carbon emissions.

Petrochemical manufacturers in Thailand normally have their own environmental data protection measures in order to be able to conform to the current environmental laws and regulations. Never before has the environmental performance of the entire Thai petrochemical industries been brought together and evaluated. The real carbon emissions caused by these industries have never been examined. It is, therefore, the first priority to establish a carbon budget of these industries. For the most complete inventory, an attempt had been made to collect data of many products as possible. The select petrochemical industries are listed below:

- **Upstream petrochemical industry:** benzene, butadiene, ethylene, mixed C4, mixed xylene, propylene, p-xylene, and toluene
- **Intermediate petrochemical industry:** acetone, bisphenol A, ethylene glycol (EG), ethylene oxide (EO), phenol, phthalic anhydride (PA), polyol, purified terephthalic acid (PTA), and styrene monomer (SM)
- **Downstream petrochemical industry:** acrylonitrile butadiene styrene (ABS), butyl methacrylate (BMA), polybutadiene rubber (BR), compounded plastic, epoxy, high density polyethylene (HDPE), low density polyethylene (LDPE), linear low density polyethylene (LLDPE), polycarbonate (PC), methyl methacrylate (MMA), nylon 6, polyethylene terephthalate (PET), polyacetal, polyester, polypropylene (PP), polystyrene (PS), polyurethane (PU), styrene acrylonitrile (SAN), superabsorbent, and vinyl cis polybutadiene rubber (VCR)
- **Plastics and derivative industry:** blown film, pipe compound, nitrile latex

Figures 2.1 shows the flow diagram of the petrochemical industries.

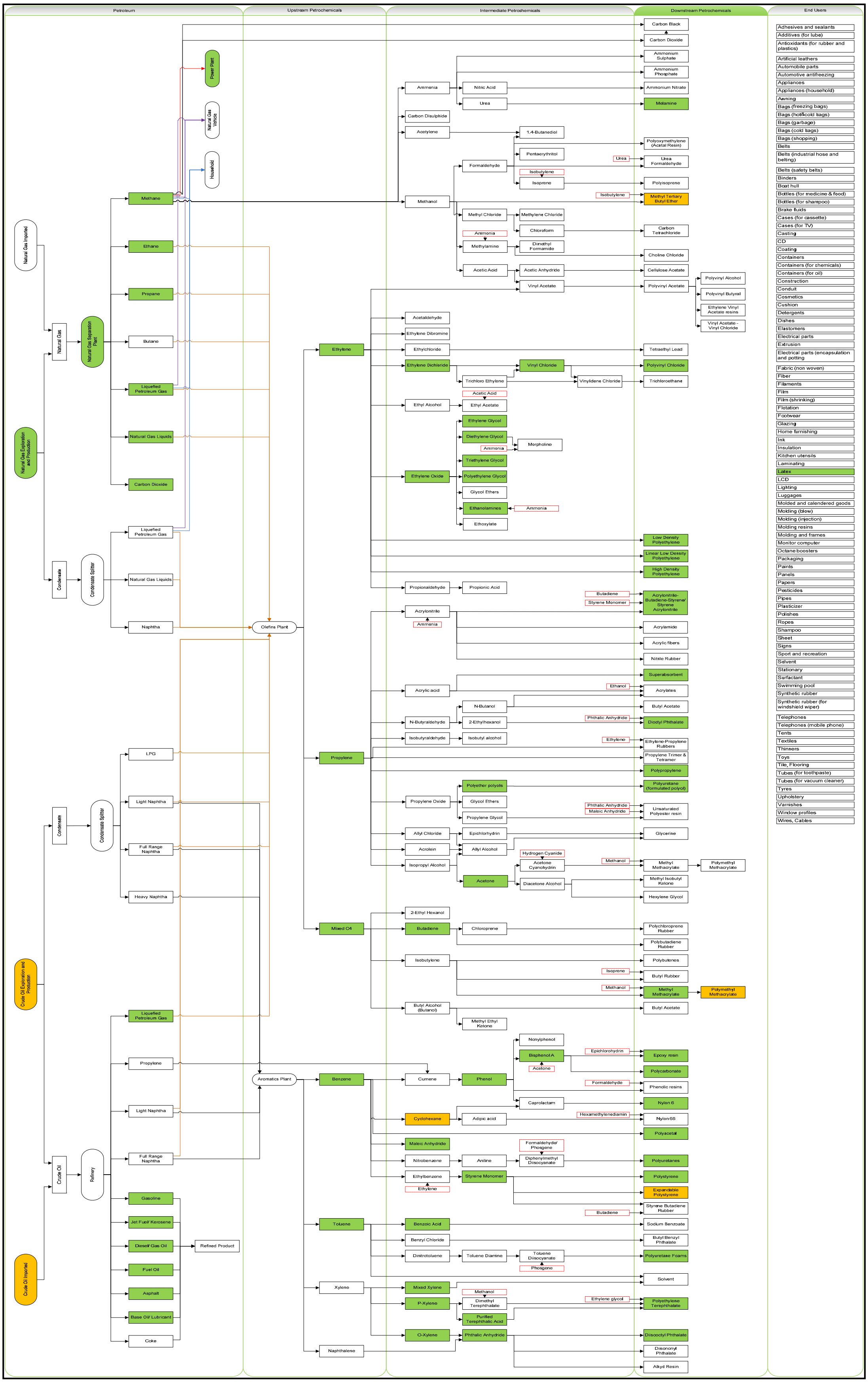
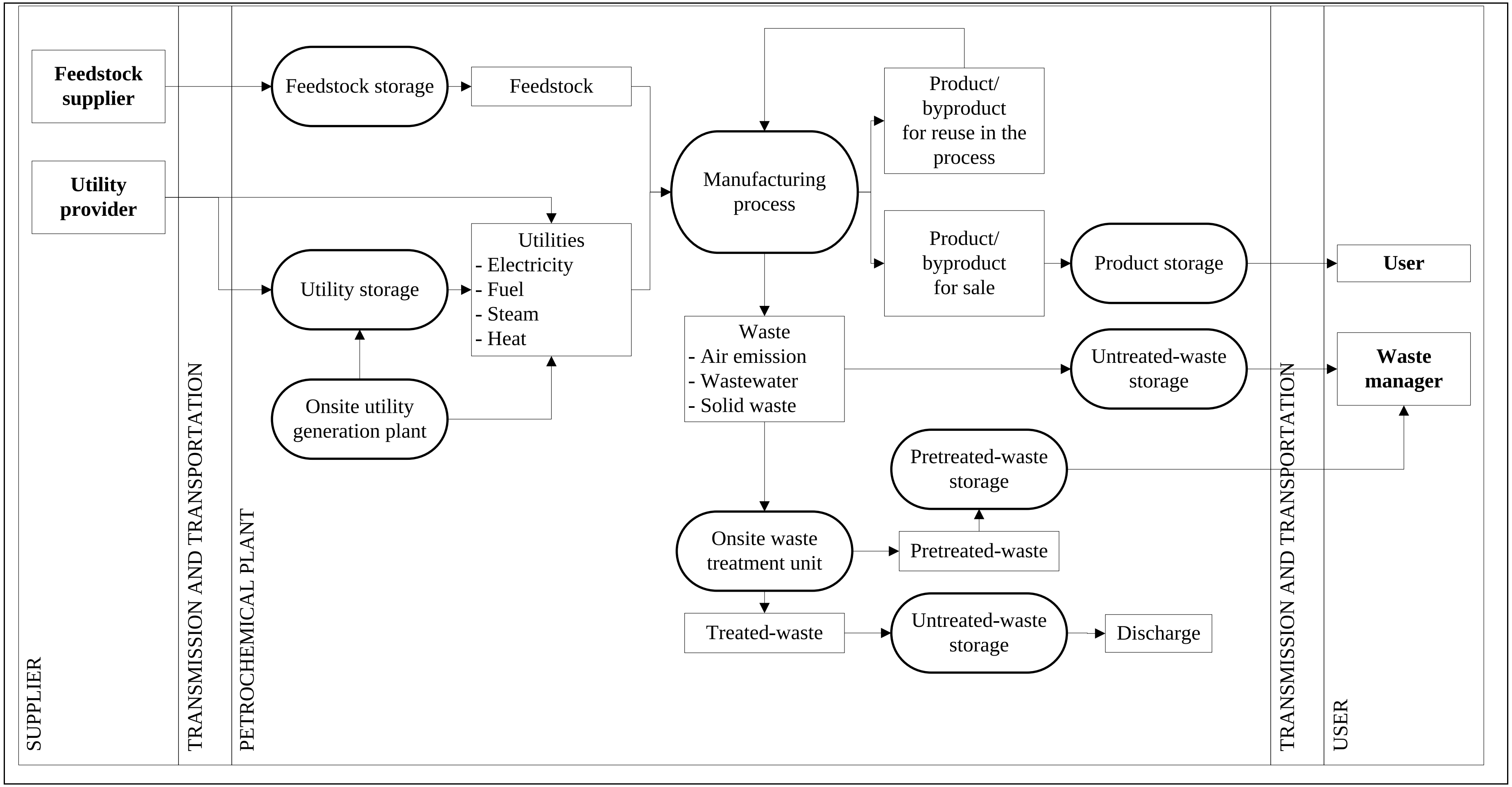


Figure 2.1 Petrochemical industry flow chart

This study excluded carbon emissions from petroleum refining as such figures were already calculated (National Metal and Materials Technology Center, 2008). Fertilisers derived from natural gas were excluded because, in Thailand, they were not considered to be part of the petrochemical chain. Methanol production was also excluded due to data unavailability. The plastics and derivatives industry was not really part of the scope but a small number of examples were included to help form a view about its relative carbon intensity.

Environmental impacts occur at every stage of the product life from feedstock and energy acquisition, through manufacturing and transport, to use by customers, and finally, disposal at the end of its life. Consequently, in order to assess the real environmental impact of the petrochemical industries, it is advised to investigate the environmental impacts throughout their life cycle, which includes the direct emissions from the manufacturing processes and other embedded emissions such as the acquisition and transportation of feedstock, the production and transmission of utilities, transportation of product, and waste treatment and disposal as shown in Figure 2.2.

This study adopted the international practice for emission inventory development such as 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, and Climate Leaders Greenhouse Gas Inventory Protocol of United States Environmental Protection Agency (USEPA).



<u>Figure 2.2</u> Basic input and output stream of the petrochemical plant

2.2 FUNDAMENTAL CONCEPTS

2.2.1 Conservative concept

One of the major concerns about environmental protection and management is the underestimation of the emission inventory which results from various factors including the incompleteness of data. In order to ensure correct measures for the possible worst scenarios, the conservative concept was applied in this study. The concept bases on maximising the possibility of the negative environmental impacts. The result may be worse than the actual situation but it will help in, firstly, preparing the appropriate measures that can handle the potentially serious circumstances; and, secondly, it can aid in convincing the industries to provide higher quality data. An example of the conservation concept is to estimate missing emission data by scaling from the available data of the nearest process, i.e. we assume an emission has occurred even if one has not been recorded.

2.2.2 Carbon capture and storage

Carbon capture and storage (CCS) technology separates and captures carbon dioxide from emission sources, then stores it in geological reservoirs, such as depleted oil, gas fields and deep saline aquifers. The use of CCS is considered as one of the options in the portfolio of measures for stabilisation of greenhouse gas concentrations while the use of fossil fuels continues (IPCC, 2006b).

If there is CCS technology installed and used at the plant, the amount of CO_2 and other gases captured must be deducted from the total emissions. However, the amount of CO_2 captured for later use or for short-term storage should not be deducted. Further detail about CCS is described in section 5.2.2.1 of Chapter 5.

2.2.3 Main categories of emissions

Generally, there are 2 main categories of emissions: direct emissions and indirect emissions. The definitions are given in Box 2.1.

<u>**Box 2.1**</u>

Definitions of direct emissions and indirect emissions

The USEPA's climate leaders greenhouse gas inventory protocol provided the definitions as follow:

Direct emissions are emissions from sources that are owned or controlled by the company, e.g. emissions from combustion in owned or controlled boilers, furnaces, vehicles; emissions from chemical production in owned or controlled process equipment.

Indirect emissions are a consequence of the activities of the company, but occur at sources owned or controlled by another company. An example of indirect emissions is the emissions from the generation of procured electricity consumed by a company.

Source: USEPA, 2008.

From Figure 2.2, the petrochemical industries have the relevant emission sources as follow:

2.2.3.1 <u>Direct emissions</u>

2.2.3.1.A) *Emissions from industrial process*

i) Emissions from industrial processing

ii) Emissions from fuel used in the process

iii) Flared emissions

2.2.3.1.B) *Emissions from energy sector*

iv) Emissions from the generation of on-site utilities such as electricity, heat and steam

2.2.3.1.C) *Other emissions*

v) Emissions from the transmission and distribution of feedstocks, products, and waste controlled by the company

vi) Emissions from the transportation of employees

vii) Fugitive emissions which result from both intentional or unintentional releases e.g. storage tank leakage

viii) Emissions from non-routine activities such as maintenance activities, turn around, upset conditions

2.2.3.2 Indirect emissions

2.2.3.2.A) *Emissions from energy sector*

i) Emissions from the generation of procured utilities such as electricity, heat and steam

2.2.1.1.B) *Other emissions*

ii) Emissions from the generation of procured feedstock

iii) Emissions from transmission and distribution of utilities, feedstocks, products, and waste by another company

iv) Emissions from off-site waste disposal

2.2.4 Emission intensity

Emission intensity is the average emissions rate of a given pollutant from a given source relative to the intensity of a specific activity; for example grammes of carbon dioxide released per megajoule of energy produced, or the ratio of greenhouse gas emissions produced to gross domestic product (GDP). Emission intensity is used to derive estimates of air pollutant or greenhouse gas emissions based on the amount of fuel combusted, on industrial production levels, or similar activity data. Emission intensity may also be used to compare the environmental impact of different fuels or activities.

In this study, carbon emission intensity is employed and is defined as the average carbon dioxide and other greenhouse gases relating to the production of the petrochemical industries. The unit is kilotonne of CO_2eq per kilotonne of petrochemical production. Carbon emission intensity and emission intensity were often used interchangeably in this study.

2.2.5 Double counting and omission

It is necessary to avoid double counting and omission in the development of carbon budget. A checklist of all emissions sources is recommended. Missing data should be noted and where possible a conservative, plausible, alternative estimate made.

In addition, IPCC defined fuel combustion as the intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process, or for use away from the apparatus (IPCC, 2006a). This definition aims to separate the combustion of fuels for distinct and productive energy use from the heat released from the use of hydrocarbons in chemical reactions in industrial processes, or from the use of hydrocarbons as industrial products.

2.3 SCOPE OF THE STUDY

This study focuses on the production processes only. It does not cover the construction or transportation phase due to the unavailability of suitable data. The data used were the gate-to-gate data of the petrochemical plant. The outcome of the study shows the aggregated emissions of the entire industries comprising the upstream, intermediate and downstream petrochemical industries and the plastics and derivative industries for the confidentiality reason.

2.4 WORKING STEPS AND THE OVERVIEW OF THE METHODOLOGY

2.4.1 Working steps

There were 5 steps to develop the carbon budget: data collection, calculation of emissions, data allocation, uncertainty analysis, and data compilation.

2.4.1.1 Data collection

This study collected the industrial data at company level. The data was from the environmental impact assessment (EIA) reports, which the industries directly submitted to the government agencies. Thus, the data was acceptable to both the individual company and the Thai government.

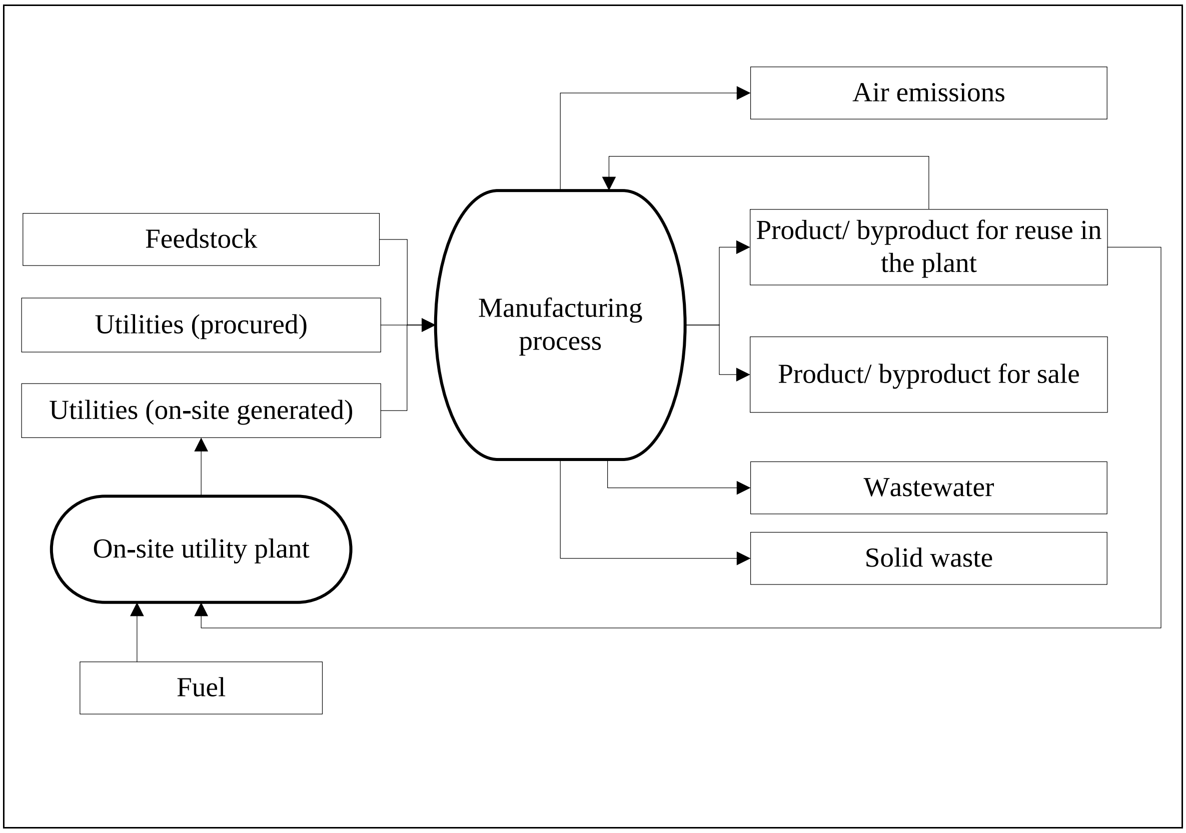


Figure 2.3 Basic material flow diagram of a manufacturing plant

Considering the basic material flow of the industries as shown in Figure 2.3, key parameters to be collected were:

2.4.1.1.A) *Input stream*: feedstock, on-site utilities, and procured utilities. Data needed were source and consumption quantity. Relevant emission factors were optional.

2.4.1.1.B) *Output stream*: product and waste stream. Data needed were the amount of product and byproduct being exported as well as that being reused in the plant. For the waste stream, the amount of greenhouse gases namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were the core emission data to be collected. Other emission parameters such as carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and chemical oxygen demand (COD) were also collected.

The data to be collected from the industries were summarised in Table 2.1.

Table 2.1 Summary of data collection

Items	Core	Optional
Input stream		
Feedstock	• Consumption quantity • Source	• Relevant emission factor
Procured utilities		
On-site utilities		
Output stream		
Product	• Total production quantity • Export quantity • Reused quantity	
Byproduct		
Air emission	• Quantity of – CO_2 – CH_4 – N_2O	• Quantity of – CO – NMVOC
Wastewater	• Quantity of COD	
Solid waste		• Solid waste quantity

2.4.1.2 Calculation of emissions

The collected data was often found incomplete. In the case that data of core emissions were not provided, they must be calculated. Section 2.5 and 2.6 illustrate methodology of air emissions and wastewater calculation.

2.4.1.3 Data allocation

In many petrochemical industries, particularly in the upstream phase, not only one but several products are produced at the same time. Therefore, environmental loading should be allocated to each product fairly. A mass allocation was applied in this study. The allocation concept was to allocate environmental loading to every item that was generated by the process and was exported out of the plant. This included products and wastes code A1-A6 as listed in Table 2.2. The environmental loading should not be allocated to products or waste code N1-N2. Table 2.3 shows the example of allocation template.

Table 2.2 List of allocation code

Code	Definition
A1	Main product
A2	Byproduct having market value
A3	Byproduct sent to other plants as raw material or alternative fuel e.g. fuel oil, fuel gas, vent gas
A4	Off spec product that is saleable
A5	Process waste sent to other plants as raw material or alternative fuel e.g. plastic scrap
A6	Process waste being recycled outside the plant
N1	Byproduct being recycled or reused in the process
N2	Process waste being recycled or reused in the process
N3	Solid waste that does not originally produced by the process even they can be further recycled or saleable e.g. metal scrap

Sometime exported byproduct data was not available; the environmental loading was therefore allocated to main product(s). In this regard, this should be noted as it is one of the sources of error and leads to overestimation of the environmental loading of the main products. However, it was acceptable based on the conservation concept. In addition, it could be considered as the motivation to the industries to provide higher quality data.

2.4.1.4 Uncertainty analysis

Uncertainty analysis aimed to identify the source of error and to help in prioritising the improvement of the carbon budget. Section 2.7 provides further detail of uncertainty analysis.

2.4.1.5 Data compilation

At this step, all environmental loading parameters were converted to a unit of carbon dioxide equivalent (CO_2eq) to obtain the carbon budget of each product. Then, data of all product were combined together to obtain the carbon budget of the entire industries. Further detail is described in section 2.8.

Table 2.3 Example of data allocation template

Items	Source	Amount	Unit	Main Product		Byproduct		Off-Spec Product	Process Waste	
				A1	N1	A2	A3	A4	A5	A6
				Sold	Reused in process	Sold	Sent to other plant as row material/ fuel	Sold	Sold as off-spect	Recyclable
				Product 1	**Fuel**	**Product 2**	**Fuel gas**	**Product 3**	**Waste 1**	**Waste 2**
PRODUCTION										
Production rate										
Production ratio										
AIR EMISSION										
CO										
CO_2										
CH_4										
N_2O										
NMVOC										
WASTEWATER										
COD										
SOLID WASTE										
Solid waste1										
Solid waste2										

2.4.2 Overall emissions

There are two important terms that are commonly found in the estimation of emissions: activity data and emission factors. The definitions of these two terms are given in box 2.2.

Box 2.2

Definition of activity data and emission factor

Activity data (AD) are data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time.

Emission factor (EF) is the average emission rate of a given greenhouse gas for a given source, relative to units of activity.

Source: IPCC, 2006.

To the extent possible, measured emission data should be used in the carbon budget development. However, if such data were not available, emissions could be estimated by multiplying the activity data with an appropriate emission factor as shown in Equation 2.1.

Equation 2.1

Emissions of greenhouse gas i

$$E_i = AD \times EF_i$$

Where

E_i : Emissions of greenhouse gas i

AD : Activity data

EF_i	:	Greenhouse gas i emission factor
i	:	Type of greenhouse gas

There were 4 tiers to select the emission factor based on the specificity of the data. The higher tier gave more accurate result and less uncertainty. The activity data should be disaggregated to correspond with the more specific emission factor.

Tier 1: Default emission factor

Tier 2: Country specific emission factor

Tier 3: Technology specific emission factor

Tier 4: Plant specific emission factor

All of the default emission factors used in this study are provided in this report. However, for confidentiality reason, technology and plant specific data could not be displayed. Some of country specific data are shown in the aggregate level. In some cases, unit conversion was required to adjust data to the same units used in emission factors.

Total emissions at the industrial plant are the sum of airborne emission, emission from wastewater and emission from solid waste as shown in Equation 2.2. All sources of emissions should be converted to the same unit that is carbon dioxide equivalent (CO_2eq).

Equation 2.2

Total emissions at the industrial plant

$$E_{Total} = E_{Air} + E_{Wastewater} + E_{Solid\ waste}$$

Where

E_{Total}	:	Total emissions, tonne CO_2eq
E_{Air}	:	Airborne emissions, tonne CO_2eq
$E_{Wastewater}$	:	Emissions from wastewater, tonne CO_2eq
$E_{Solid\ waste}$	:	Emissions from solid waste, tonne CO_2eq

Section 2.5 and 2.6 provide the estimation methodology for airborne emission and emission from wastewater respectively.

2.4.3 Main assumptions

There were a number of assumptions that have been made in this study.

2.4.3.1 Carbon capture and storage (CCS)

If CCS was not reported, it was assumed that there was no CCS taking place.

2.4.3.2 Utilities

In case source of utilities was not identified, it was assumed that the consumed utilities were from an outside source.

2.4.3.3 Fugitive emissions

Fugitive emissions should be taken into account in the development of the emission budget. However, based upon the available data, it was relatively small comparing to emissions from other sources. Therefore, in those cases where the industrial fugitive data was not identified, it was assumed to be zero.

2.4.3.4 Solid waste

As the obtained data on this waste category was insufficient and based on the observation that when reported its amount was negligible in comparison to emissions from other sources: emissions from solid waste was omitted in this study. However, revision to the carbon budget would be encouraged once more data is available.

2.5 AIRBORNE EMISSION CALCULATION

Air emissions of the petrochemical industries are from both direct and indirect emissions. However, for the ease of calculation, this section had grouped the airborne emissions into emissions from energy sector and emissions from industrial process.

2.5.1 Calculation of emissions from energy sector

Energy sector is one of the most important sectors in greenhouse gas emission inventories (IPCC, 2006a). Some of the petrochemical plants had their own on-site energy plants to support their primary activities or for sale. Some imported the energy from outside sources such as the national grid or individual utility providers. Main emissions from the energy sector relevant to the petrochemical industries are associated with fuel, electricity, and steam consumption. Methodologies described in this section applies to both on-site and procured utility.

2.5.1.1 Emissions associated with consumed fuel

Combustion of fossil fuel typically generates carbon dioxide (CO_2) and water (H_2O) and releases chemical energy in the fuel as heat. The heat can be used directly in the manufacturing process or used to produce other form of energy such as electricity or transportation. Emissions of CO_2 mainly depend on the carbon content of the fuel but also depends on combustion efficiency. Some carbon can be released as carbon monoxide (CO), methane (CH_4) or non-methane volatile organic compounds (NMVOCs). Most of them oxidise to CO_2 in the atmosphere. In case of fuel combustion, the emissions of these non-CO_2 gases contain very small amounts of carbon compared to the CO_2 estimate (IPCC, 2006a).

In general, emissions from fuel combustion could be estimated from multiplying fuel consumption quantity by the corresponding emission factors. Emission factor for CO_2 strongly depends on the type of fuel while emission factors of other gases vary with combustion technologies and operating conditions. This study focuses on the CO_2 estimation where emission factors could be calculated or were known. However, it is recommended to estimate other non-

CO_2 greenhouse gases when specific emission factors of these gases are available. Use of averaged emission factors for these gases will introduce relatively large uncertainties.

There were 4 steps to estimate emissions from fuel combustion.

Step 1: Identify consumption quantity of each fuel type in energy unit e.g. megajoule (MJ) and combustion efficiency. The default assumption was complete combustion. In case the fuel consumption was given in mass or volume unit, energy content of each fuel (Table 2.4) was used to convert these data to energy units.

Table 2.4 **Energy content by type of fuel**

Type of fuel	Energy Content				
	Default		Country Specific		Source
Coal					
Anthracite	26.70	MJ/kg			(b)
Bituminous	25.80	MJ/kg			(b)
Imported			26.37	MJ/kg	(a)
Lignite			13.72	MJ/kg	(a)
Sub-bituminous	18.90	MJ/kg			(b)
Ethane	46.40	MJ/kg			(b)
Natural Gas	48.00	MJ/kg			(b)
Petroleum Products					
Crude oil	42.30	MJ/kg			(b)
Diesel			36.42	MJ/l	(a)
Fuel oil			39.77	MJ/l	(a)
Fuel oil (A)			38.18	MJ/l	(a)
Fuel oil (C)			41.28	MJ/l	(a)
Gasoline			31.48	MJ/l	(a)
Kerosene			34.53	MJ/l	(a)
Liquefied petroleum gas			50.22	MJ/kg	(a)
(LPG)			26.62	MJ/l	(a)

Source: (a) Department of Alternative Energy Development and Efficiency (DEDE), Thailand, 2005

(b) IPCC, 2006

Step 2: Select appropriate emission factor. There were 3 tiers for emission factors.

Tier 1**:** Default emission factor by fuel (Table 2.5)

Tier 2: Country specific emission factors by fuel

Tier 3: Plant specific emission factors

Table 2.5 Default emission factor by type of fuel

Type of fuel	Emission Factor (gCO_2eq/MJ)	Source
Coal		
Lignite	101.00	(a)
Anthracite	98.30	(a)
Bituminous	94.60	(a)
Sub-bituminous	96.10	(a)
Ethane	61.60	(a)
Natural Gas	56.10	(a)
Petroleum Products		
Coke	102.78	(b)
Crude oil	73.30	(a)
Diesel	74.10	(a)
Fuel oil (heavy)	74.05	(c)
Fuel oil (light)	73.16	(c)
Kerosene	71.90	(a)

Table 2.5 Default emission factor by type of fuel (cont.)

Type of fuel	Emission Factor (gCO_2eq/MJ)	Source
Liquefied petroleum gas (LPG)	63.10	(a)
Petroleum coke	94.44	(b)
Refinery gas	57.60	(a)

Source: (a) IPCC, 2006

(b) Carbon trust, 2006

(c) Aube, 2001

Step 3: Calculate emissions by multiplying the amount of fuel consumption by the selected emission factor as shown in Equation 2.3

Equation 2.3

Greenhouse gas emissions associated with consumed fuel

$$Efuel_{ij} = FC_j \times EF_{ij}$$

Where:

$Efuel_{ij}$	:	Emissions of greenhouse gas i associated with consumed fuel j, tonne
FC_j	:	Consumption quantity of fuel j, MJ
EF_{ij}	:	Greenhouse gas i emission factor of fuel j, tonne/MJ
i	:	Type of greenhouse gas
j	:	Type of fuel

Step 4: Calculate total greenhouse gas emissions associated with consumed fuel by combining emissions from all types of consumed fuel.

Equation 2.4

Total greenhouse gas emissions associated with consumed fuel

$$Efuel_{Total} = \sum_{j}\sum_{i} Efuel_{ij}$$

Where

$Efuel_{Total}$	:	Total greenhouse gas emissions associated with consumed fuel, tonne
$Efuel_{ij}$	:	Emissions of greenhouse gas i associated with consumed fuel j, tonne
i	:	Type of greenhouse gas
j	:	Type of fuel

If there were more than one type of emitted gases, they should be converted to CO_2eq before combining the numbers together.

2.5.1.2 Emissions associated with consumed electricity

There were 3 steps to estimate emissions associated with consumed electricity as follow:

Step 1: Identify consumption quantity of electricity in energy unit e.g. megawatt hour (MWh).

Step 2: Select appropriate emission factor. There were 4 tiers for emission factors. Tier 1-3 were default country specific emission factors for electricity generation used in this study, which were from the life cycle inventory data of Thailand's electricity grid generation systems (Varabuntoonvit, et al., 2008).

Tier 1: Default country specific emission factor for the average electricity grid (Table 2.6).

Tier 2: Default country specific emission factor for specific fuel consumed by the electricity generator (Table 2.7).

Tier 3: Default country and technology specific emission factor (Table 2.8)

Tier 4: Plant specific emission factor

Table 2.6 **Selected greenhouse gas emissions for average electricity grid in Thailand**

Greenhouse Gas	Emission Factor (tonne/MWh)
CO_2	5.47×10^{-1}
CH_4	2.77×10^{-3}
N_2O	1.23×10^{-3}
HFC134a	2.42×10^{-10}
SF_6	1.85×10^{-7}

Table 2.7 **Greenhouse gas emissions at the electricity plant sorted by fuel**

Fuel type	GHG Emission Factor (tonne CO_2eq/MWh)
Coal	1.125792
Gas	0.868993
Oil	1.509000
Hydro	0.015100

Table 2.8 **Greenhouse gas emissions for specific power plant type**

Power plant type		GHG Emission Factor (tonne CO_2eq/MWh)
Coal		1.125792
Gas	Steam turbine	0.681390
Gas	Gas turbine	0.868993
Gas	Combined cycle	0.511010
Gas	Independent power producer	0.521090
Oil	Steam turbine	1.291970
Oil	Gas turbine	1.509000
Oil	Diesel	0.724000
Hydro		0.015100

Step 3: Estimate greenhouse gas emissions by multiplying the amount of electricity consumption by the selected emission factors as shown in Equation 2.5.

<u>Equation 2.5</u>

Greenhouse gas emissions associated with consumed electricity

$$Eelec_i = EC \times EF_i$$

Where:

$Eelec_i$	:	Emissions of greenhouse gas i associated with consumed electricity, tonne
EC	:	Electricity consumption, MWh
EF_i	:	Greenhouse gas i emission factor, tonne/MWh
i	:	Type of greenhouse gas

2.5.1.3 Emissions associated with consumed steam

Emissions from consumed steam could be estimated based on boiler efficiency and fuel emission factors (USEPA, 2005). There were 3 estimation steps as follow:

Step 1: Identify consumption quantity of steam. If the obtained data was in mass or volume unit, it should be converted to energy unit. It can be done by:

<u>Tier 1</u>: Use specific enthalpy of steam (Figure 2.4) where operating condition was provided.

<u>Tire 2</u>: Use specific energy content of steam provided by steam generator.

Step 2: Identify boiler efficiency. Boiler efficiency (BF) should be provided by steam supplier or can be estimated by Equation 2.6 otherwise the default value of 80% was applied.

<u>Equation 2.6</u>

Boiler efficiency

$$\mathrm{BF} = \frac{\text{Steam energy}}{\text{Fuel energy}}$$

Where:

BF	:	Boiler efficiency
Steam energy	:	Energy exported in steam, MJ
Fuel energy	:	Energy provided by fuel, MJ

Step 3: Identify type of fuel consumed in the steam generation and determine the appropriate emission factor. Default fuel type was natural gas.

Step 4: Calculate greenhouse gas emissions by using Equation 2.7

<u>Equation 2.7</u>

Greenhouse gas emissions associated with consumed steam

$$Esteam_{ij} = \frac{SC}{BF} \times EF_{ij}$$

Where

$Esteam_{ij}$	:	Emissions of greenhouse gas i associated with consumed steam and with fuel j consumed in the steam generation, tonne
SC	:	Steam consumption, MJ
BF	:	Boiler efficiency
EF_{ij}	:	Greenhouse gas i emission factor of fuel j, tonne/MJ
i	:	Type of greenhouse gas
j	:	Type of fuel consumed in the steam generation

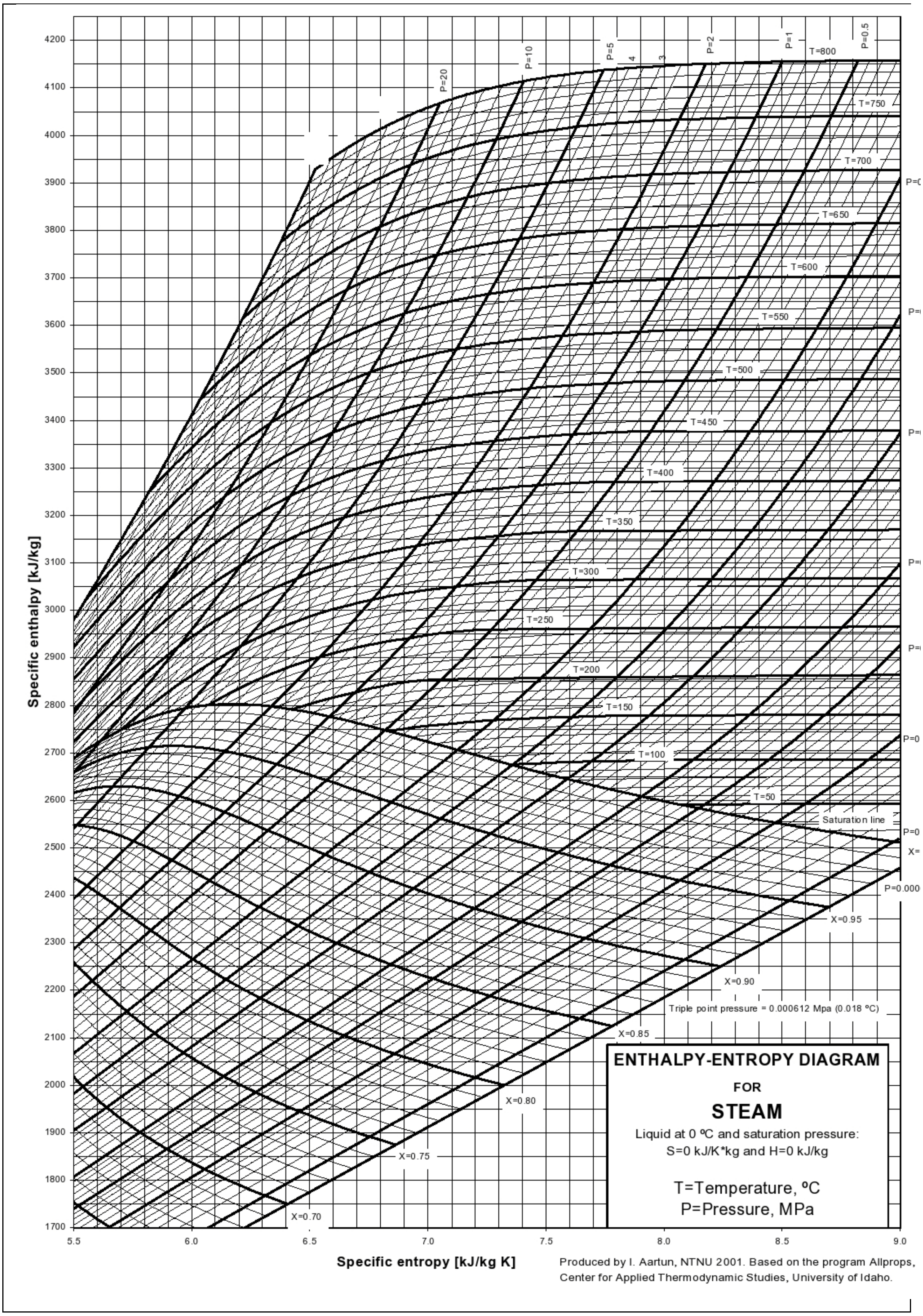


Figure 2.4 **Enthalpy-entropy diagram**

2.5.2 Calculation of emissions from industrial process

There were 4 steps to calculate emissions from industrial process.

Step 1: Identify greenhouse gas emissions from fuel or process byproducts combusted to provide thermal energy to the production process. If the data was not available, it could be calculated from Equation 2.8.

Equation 2.8

Greenhouse gas emissions from fuel or process byproduct combustion

$$Ecombustion_{Total} = \sum_{j}\sum_{i}\left(FCP_j \times EF_{ij}\right)$$

Where

$Ecombustion_{Total}$	:	Total emissions of greenhouse gas i from fuel or process byproduct j combusted to provide thermal energy to petrochemical production process, tonne
FCP_j	:	Consumption of fuel or process byproduct j in petrochemical production process, MJ
EF_{ij}	:	Greenhouse gas i emission factor of fuel or process byproduct j, tonne/MJ
i	:	Type of greenhouse gas
j	:	Type of fuel or process byproduct

Step 2: Identify greenhouse gas emissions from process vents during petrochemical production. This type of emissions should be measured directly, thus no further equation was provided.

Step 3: Identify greenhouse gas emissions from flared waste gases during petrochemical production. There were 3 tiers to determine greenhouse gas emission from flared waste gases.
Tier 1: Assume the flaring amount of 7% of total emissions. This amount is from a well-maintained ethylene plant in Norway (IPCC, 2006b). Steam cracking processes that utilise naphtha, propane, and butane feedstocks are assumed to be energy neutral, requiring no use of

supplemental fuel, therefore there are assumed to be no CO_2 emissions associated with supplemental fuel consumption for these feedstocks.

<u>Tier 2</u>: Calculate greenhouse gas emissions from flared waste gas by using Equation 2.9

<u>Equation 2.9</u>

Greenhouse gas emissions from flared waste gas

$$Eflare_{Total} = \sum_{k}\sum_{i}(A_k \times NVC_k \times EF_{ik})$$

Where

$Eflare_{Total}$	:	Total emissions of greenhouse gas i from flared waste gases k during the petrochemical production, tonne
A_k	:	Amount of flared waste gas k during the petrochemical production, tonne
NCV_k	:	Net calorific value of flared waste gas k, MJ/tonne
EF_{ik}	:	Greenhouse gas i emission factor of flared waste gas k, tonne/MJ
i	:	Type of greenhouse gas
k	:	Type of flared waste gas

<u>Tier 3</u>: Use reported amount of greenhouse gas emissions from flared waste gases.

Step 4: Calculate greenhouse gas emissions from petrochemical industrial process by using Equation 2.10.

<u>Equation 2.10</u>

Greenhouse gas emission from petrochemical industrial process

$$Eind = Ecombustion + Event + Eflare$$

Where

Eind	:	Greenhouse gas emissions from the petrochemical industrial process, tonne
Ecombustion	:	Greenhouse gas emissions from fuel or process byproducts combusted to provide thermal energy to the petrochemical production process, tonne
Event	:	Greenhouse gas emissions from process vents during the petrochemical production, tonne

Eflare : Emissions from flared waste gases during the petrochemical production, tonne

2.6 EMISSION FROM WASTEWATER

Industrial wastewater can be a source of methane (CH_4) when treated or disposed anaerobically (IPCC, 2006c). This study focused on estimating CH_4 emissions from on-site industrial wastewater treatment, which could be determined from the amount of degradable organic material in the wastewater. Common parameters used to measure the organic component of wastewater are biochemical oxygen demand (BOD) and chemical oxygen demand (COD). As BOD measures amount of biodegradable substances only, while COD measures both biodegradable and non-biodegradable; based on the conservative concept, COD was employed in this study.

Sludge and CH_4 generated at the wastewater facilities could be recovered and combusted in a flare or energy device. The amount of CH_4 that was flared or recovered for energy use should be subtracted from total emissions. Default assumption was no CH_4 recovery or combustion. And default sludge removal was zero.

There were 3 steps to calculate CH_4 emission from industrial wastewater.

Step 1: Estimate total organically degradable carbon in wastewater by using Equation 2.11.

Equation 2.11

Organically degradable material in industrial wastewater

$$TOW = W \times COD$$

Where:

TOW	:	Total organically degradable material in wastewater from the industrial production, tonne COD
W	:	Wastewater generated, m^3
COD	:	Chemical oxygen demand, tonne COD/m^3

The amount of COD and wastewater outflow were normally reported in the EIA report. In the case that COD and wastewater data were not identified, the following default data for plastics and resins industry could be used (IPCC, 2006c) – Table 2.9.

Table 2.9 Default data for plastics and resins industries

Parameter	Value	Range	Unit
Wastewater generation	0.6	0.3 – 1.2	m^3/tonne of product
COD	3.7	0.8 – 5	kg/m^3

Step 2: Identify emission factor. If specific emission factor was not available, it could be estimated by using maximum methane producing capacity (B_o) and methane correction factor as shown in Equation 2.12.

Equation 2.12

Emission factor for industrial wastewater

$$EF_w = B_o \times MCF_w$$

Where

EF_w	:	Emission factor for each treatment/discharge pathway or system, tonne CH_4/tonne COD
B_o	:	Maximum methane (CH_4) producing capacity, tonne CH_4/tonne COD
MCF_w	:	Methane correction factor
w	:	Each treatment/discharge pathway or system

Methane correction factor (MCF) is a fraction of waste treated anaerobically. It indicates the extent to which B_o is realised in each type of treatment method. Thus, it is an indication of the degree to which the system is anaerobic.

It is suggested to use the country or plant specific data to determine both B_o and MCF. However, if the specific data were not available, the IPCC default data of 0.25 kg CH_4/kg COD for B_o can be applied. Table 2.10 shows default MCF values based on the expert judgement (IPCC, 2006c).

Table 2.10 Default MCF values for industrial

Type of Treatment and Discharge Pathway or System	Comments	MCF	Range
Untreated			
Sea, river and lake discharge	Rivers with high organics loading may turn anaerobic, however is not considered here.	0.1	0 – 0.2
Treated			
Aerobic treatment plant	Must be well managed. Some CH_4 can be emitted from settling basins and other pockets.	0	0 – 0.1
Aerobic treatment plant	Not well managed. Overloaded	0.3	0.2 – 0.4
Anaerobic digester for sludge	CH_4 recovery not considered here	0.8	0.8 – 1.0
Anaerobic reactor (e.g. fixed film reactor)	CH_4 recovery not considered here	0.8	0.8 – 1.0
Anaerobic shallow lagoon	Depth less than 2 metres, use expert judgement	0.2	0 – 0.3
Anaerobic deep lagoon	Depth more than 2 metres	0.8	0.8 – 1.0

Step 3: Estimate methane (CH_4) emissions by using Equation 2.13.

Equation 2.13

Total methane (CH_4) emissions from industrial wastewater

$$Ew_{CH_4} = (TOW - S)EF_w - R$$

Where

Ew_{CH_4}	:	Total methane (CH_4) emissions from industrial wastewater, tonne CH_4
TOW	:	Total organically degradable material in wastewater, tonne COD
S	:	Organic component removed as sludge, tonne COD
EF_w	:	Emission factor for treatment/discharge pathway or system(s) used, tonne CH_4/tonne COD *If more than one treatment practice is used in an industry this factor would need to be a weighted average.*
R	:	Amount of CH_4 recovered in inventory year, tonne CH_4

2.7 UNCERTAINTY ANALYSIS

The uncertainty analysis aims to identify the source of error and to help prioritise the improvement of the carbon budget.

2.7.1 Decision tree for estimating the missing parameter

There was a case that carbon emissions of a certain petrochemical plant were not reported and could not be estimated because other relevant information i.e. consumed utilities were absent. However, these missing emissions so-called “the unknown” could be estimated by using data of other petrochemical plant(s) so-called “the known”.

2.7.1.1 Selection of data source

It was preferable to estimate carbon emissions by using relevant information of the same petrochemical plant. However, if missing emissions must be calculated from other petrochemical plant(s), the alternative source of data should be selected by using the following selection tiers.

Tier 1: Petrochemical plant producing different product but having similar process

Tier 2: Petrochemical plant producing same product but having different process

Tier 3: Petrochemical plant producing same product and having similar process

Tier 4: Petrochemical plant producing same product and having same process

2.7.1.2 Estimation methodology

In general, there were 3 estimation methodologies based on the number of petrochemical plant(s) that their data were used for estimating the unknown.

2.7.1.2.A) *If there was 1 plant,* the unknown was directly scaled from the known data. An example of this case is shown in Box 2.3

Box 2.3

Example of scaling the unknown from the known data

Table 2.11 Data for an example of scaling the unknown from the known data

Item	Unit	Petrochemical Plant	
		A	B
Production	ktonne/y	50.00	20.00
Carbon emissions	ktonne CO_2eq/y	37.50	unknown

By using carbon emissions of the known and production of both plants, carbon emissions of petrochemical plant B are:

$$= \frac{(37.50 \text{ ktonne } CO_2\text{eq/y})}{(50 \text{ ktonne/y})} \times (20 \text{ ktonne/y})$$

$$= 15.00 \quad \text{ktonne } CO_2\text{eq/y}$$

2.7.1.2.B) *If there were 2 plants,* a range of the unknown were scaled from the known data. An example of this case is shown in Box 2.4

<u>Box 2.4</u>

Example of estimating the unknown by employing a range of known emission intensity

<u>Table 2.12</u> Data for an example of estimating the unknown by employing a range of known emission intensity

Item	Unit	Petrochemical Plant		
		A	B	C
Production	ktonne/y	50.00	20.00	30.00
Carbon emission intensity	ktonne CO_2eq/ktonne$_{production}$	0.75	unknown	0.82

By employing the range of known emission intensity, carbon emission intensity of petrochemical plant B is 0.75 – 0.82 ktonne CO_2eq/ktonne$_{production}$.

Thus, carbon emissions of petrochemical plant B are:

= (20×0.75) to (0.82×20) ktonne CO_2eq/y

= 15.00 to 16.40 ktonne CO_2eq/y

2.7.1.2.C) *If there were 3 plants or more,* the unknown was estimated from a graph between carbon emissions and other selected parameter. It was assumed that a correlation of all parameters was simple, thus a simple linear regression equation was applied. An example of this case is shown in Box 2.5.

Box 2.5

Example of estimation of an unknown by using a graph between production and carbon emissions

Table 2.13 **Data for an example of estimation of an unknown by using a graph between production and carbon emissions**

Item	Unit	Petrochemical Plant			
		A	B	C	D
Production	ktonne/y	50.00	20.00	30.00	60.00
Carbon emissions	ktonne CO_2eq/y	37.50	unknown	24.60	51.00

From Table 2.13, a graph between production and emissions of petrochemical plant A, C and D is plotted as shown in Figure 2.5.

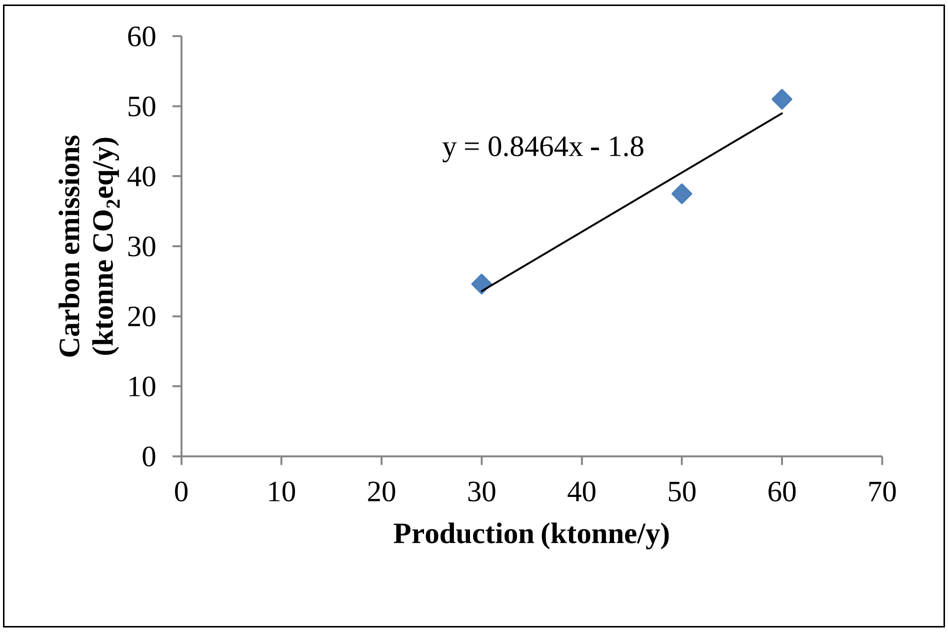


Figure 2.5 **A correlation between production and carbon emissions**

Box 2.5 (cont.)

Example of estimation of an unknown by using a graph between production and carbon emissions

It is assumed that a correlation of production and carbon emissions is simple, thus a linear regression equation is applied. The obtained equation is $y = 0.8464x - 1.8$.

Therefore, carbon emissions of petrochemical plant B are:

$= (0.8464 \times 20) - 1.8$ ktonne CO_2eq/y

$= 15.13$ ktonne CO_2eq/y

2.7.1.3 Procedure for carbon emission estimation

Based on data availability, procedure for estimating carbon emissions of a petrochemical plant was developed as illustrated in Figure 2.6. The procedure comprised of 10 steps. The first step involved the use of relevant information of that certain petrochemical plant i.e. consumed utilities. Other steps involved the use of relevant information of other petrochemical plant(s).

Step 1: Check whether carbon emission data of a certain petrochemical plant was available or could be estimated by using their own relevant information.

- If yes, employ that carbon emission data or use relevant information to estimate carbon emissions i.e. consumed utilities.
- If no, go to step 2.

Step 2: Check whether carbon emissions or carbon emission intensity of other petrochemical plant(s) are identified.

- If yes, go to step 3.
- If no, go to step 10.

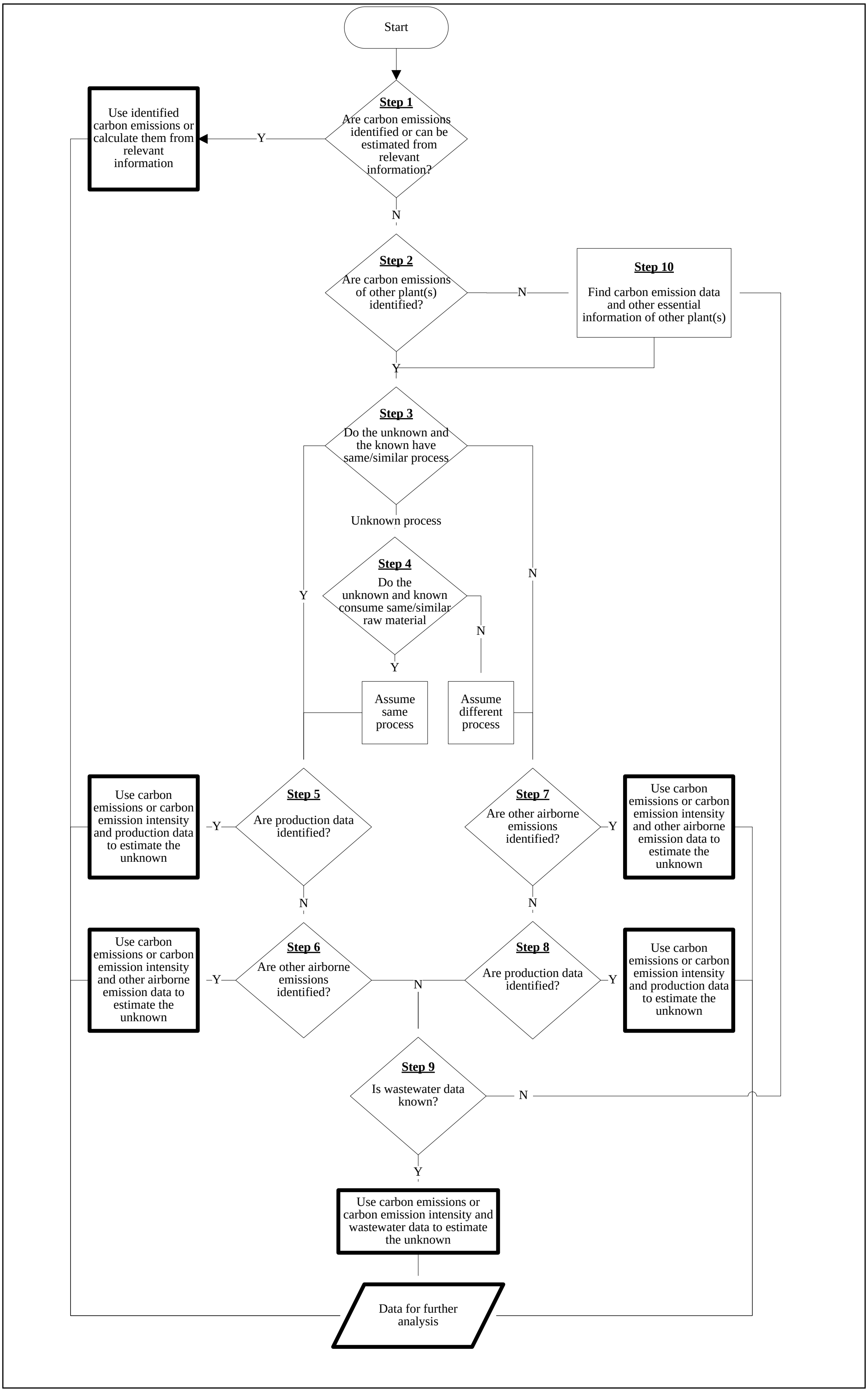


Figure 2.6 Decision tree for estimating carbon emissions of a petrochemical plant

Step 3: Check whether the unknown and the known have the same or similar production process.

- If yes, go to step 5.
- If no, go to step 7
- If the production processes are not identified, go to step 4.

Step 4: check whether the unknown and known consume same or similar raw materials

- If yes, assume they have the same or similar production process and go to step 5.
- If no or types of raw materials are not specified, assume they have different production process and go to step 7.

Step 5: Check whether petrochemical production rate of the unknown and that of the known are identified.

- If yes, use carbon emissions or carbon emission intensity and production data to estimate the unknown.
- If no, go to step 6.

Step 6: Check whether other airborne emission data of the unknown and that of the known are identified.

- If yes, use carbon emissions or carbon emission intensity and another airborne emission data to estimate the unknown.
- If no, go to step 9.

Step 7: Check whether other airborne emission data of the unknown and that of the known are identified.

- If yes, use carbon emissions or carbon emission intensity and another airborne emission data to estimate the unknown.
- If no, go to step 8.

Step 8: Check whether petrochemical production rate of the unknown and that of the known are identified.

- If yes, use carbon emissions or carbon emission intensity and production data to estimate the unknown.
- If no, go to step 9.

Step 9: Check whether wastewater data of the unknown and that of the known are identified.

- If yes, use carbon emission or carbon emission intensity and wastewater data to estimate the unknown.
- If no, go to step 10.

Step 10: Find carbon emission data and other essential information that are production rate, other airborne emission data and wastewater data. Then, go to step 3.

2.7.2 Sensitivity analysis and data selection tier

Because a number of parameters were used in the estimation of missing data, various outcomes were inevitably obtained. The selection criteria were developed and could be divided into 3 steps.

Step 1: Considering general logic

A number of graphs were used in order to estimate the unknown. The first selection tier considered the general logic of the results from the graphs, which could be classified into 5 cases.

Case 1: Normal graph

The graph was plotted, using the original data (EIA data), either between emission parameter (y axis) and another emission parameter (x axis) or emission parameter (y axis) and production rate (x axis); and if the slope was found positive then data could be interpolated – Figure 2.7.

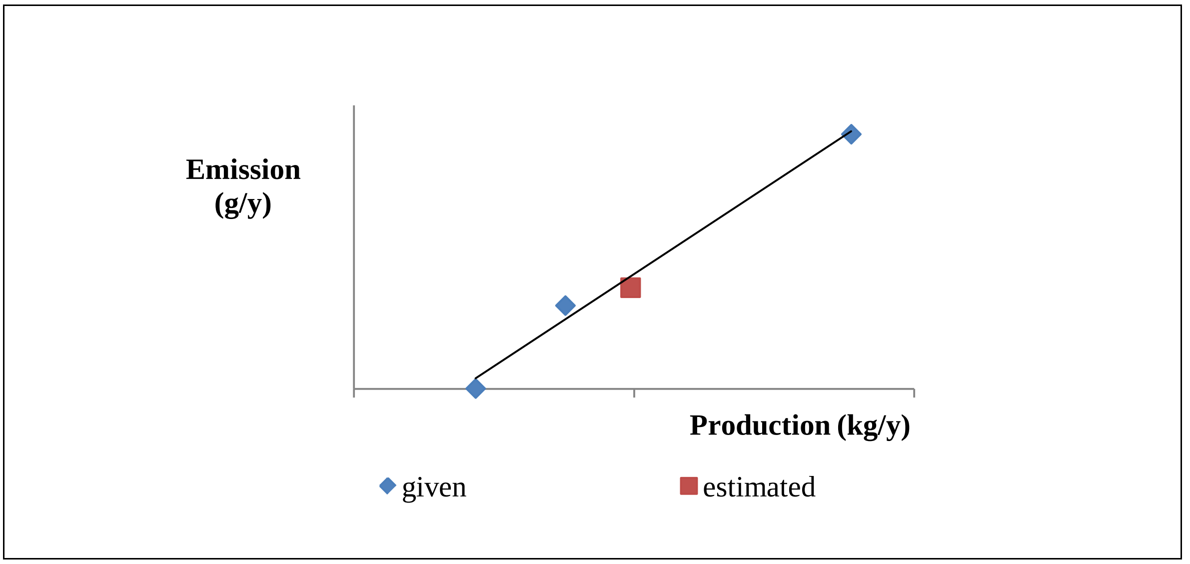


Figure 2.7 **Example of case 1 under general logic consideration**

Case 2: Negative slope (x axis was emission parameter)

The graph was plotted, using the original data, between emission parameter (y axis) and another emission parameter (x axis); and the slope was found negative – Figure 2.8. This case was possible, for example in the case that the industrial plant has installed particular pollution treatment.

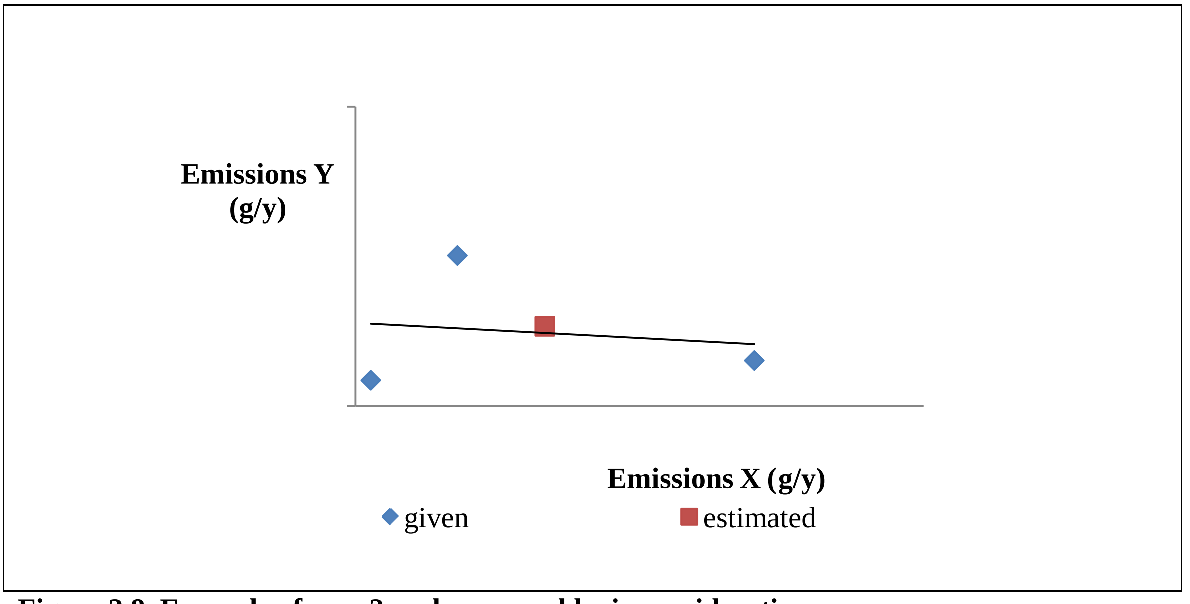


Figure 2.8 **Example of case 2 under general logic consideration**

Case 3: Negative slope (x axis was production rate)

The graph was plotted, using the original data, between emission parameter (y axis) and production rate (x axis); and the slope was found negative – Figure 2.9. This case was considered as nonsensical, because the emissions should increase corresponding to the increase of the production.

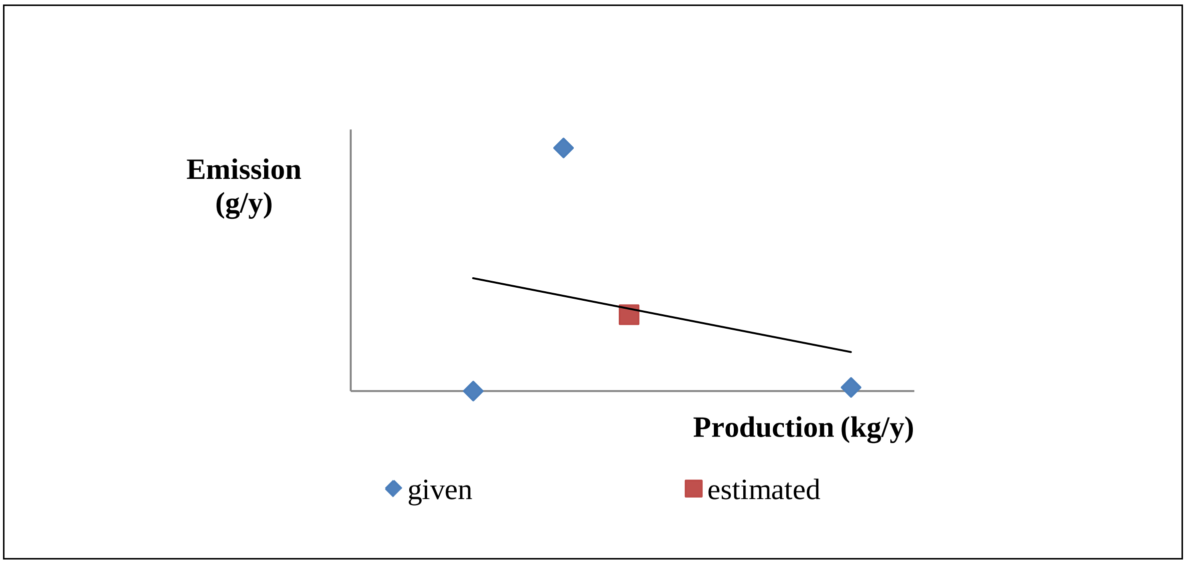


Figure 2.9 Example of case 3 under general logic consideration

Case 4: Estimation over estimation

One (or more) of the data used for plotting graphs was (were) also estimated in this study. Thus the estimates obtained would be expected to contain more uncertainty than if any of either case 1 or 2 were true.

Case 5: Negative value

The missing data was found negative in this case. However, the actual amount of emissions could not be negative. Therefore this case was illogical. Should this case be continue used, the estimates should be flagged and replaced by zero.

Based on the logic, the selection tier was:

Tier 1: Case 5 – Negative value

Tier 2: Case 3 – Negative slope (x axis = production rate)

Tier 3: Case 4 – Estimation over estimation

Tier 4: Case 2 – Negative slope (x axis = emission parameter)

Tier 5: Case 1 – Normal case

Step 2: Considering employed data

Some of the data received from the producers were questionable, for example some emissions were reported zero where actual emissions were suspected. These data were thus treated in 2 ways. First, they were considered correct and were used in the calculation just as any other data. Second, and conversely, these data were considered as erroneous and were subsequently omitted from the calculation.

For sensitivity analysis, the selection tier for this step was:

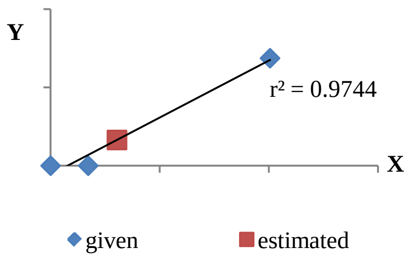
Tier 1: Case 2 – Case that omitted some given data

Tier 2: Case 1 – Case that employed all given data

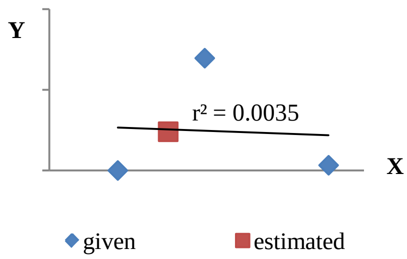
Step 3: Considering trendlines

Generally, the most preferable graph was the one that employed the given data as much as possible and yielded high value of the square of correlation coefficient (r^2). Example of this kind of graph is shown in figure 2.10 – Case 1. There was also the case that all available data were used for plotting graph but poor trendline with low r^2 was obtained (Case 2 – Figure 2.10). This implied poor correlation of data. Therefore, instead of having just 1 trendline, it might be reasonable to have several, separate trendlines (Case 3 and 4 – Figure 2.10), in which the missing data was being estimated by ratio to the most appropriate plant or product.

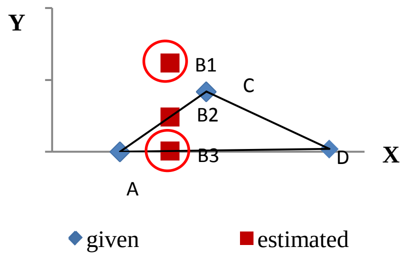
Case 1: All dots, 1 trendline, high r^2



Case 2: All dots, 1 trendline, low r^2



Case 3: Some dots with dot(s) generated from the same process



Case 4: Some dots with dot(s) generated from the different process

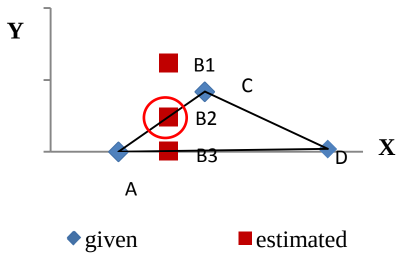


Figure 2.10 Examples of 4 cases under trendline consideration

In many cases the data used for plotting graphs were from various producers, which may or may not have the same production process as that of the plant owning the unknown. The first choice for selecting the estimated data was the one(s) obtained from the trendline(s) generated from the plants having the same process as the unknown. The later choice would be the data estimated from the trendline(s) created from the plant(s) having the different process from the unknown. For example, assuming plant B had the same process as plant D but its process was different from plant A and C, the preferred choice should be the data generated from trendlines generated from the same process (case 3) than the one(s) generated from the different process (case 4).

The selection tier of step 3 was:

Tier 1: Case 4 – Some dots with dot(s) from the different process

Tier 2: Case 2 – All dots, 1 trendline, low r^2

Tier 3: Case 3 – Some dots with dot(s) from the same process

Tier 4: Case 1 – All dots, 1 trendline, high r^2

2.7.3 Identification of the major source of error

To aid understanding, example of the calculation is given as shown in Table 2.14; however, it is noted that the real data could not be displayed due to reasons of confidentiality. The explanation of the calculation is provided as follows.

Assumption: Although data provided by the industries contained a certain range of error, that error was ignored at this stage.

Column I - IV: The emission amount of each company

The numbers in italic were obtained from the EIA report.

Column V: Calculation of the possible total emission flux

In general, total emissions flux was a sum of emissions flux from every industrial plant.

<u>Equation 2.14</u>

Total flux of emissions

$$Total\ Flux = \sum_{A} Flux_A$$

Where

$Total\ Flux$	:	Total emissions flux, tonne
$Flux_A$	:	Emissions flux of petrochemical plant A, tonne
A	:	Petrochemical plant

Because the estimates were often obtained as a range, the real emissions flux varied between the minimum and maximum value. The random function in Microsoft Office Excel was employed for calculating the possible flux value.

Table 2.14 Example of data calculation

Parameter	I	II	III	IV	V	VI	VII
	Plant A	Plant B	Plant C	Plant D	Flux		
					Flux	Flux Average	Range
X1	*70*	300,000 - 4,000,000[1)]	*500,000*	*200,000*	4,345,913 3,796,352 3,739,857 3,394,839 1,006,940	= (4,345,913 + 3,796,352 + 3,739,857 + 3,394,839 + 1,006,940) / 5 = 3,256,780	= 4,345,913 – 1,006,940 = 3,338,973
X2	*2,500*	*74,000,000*	*10,000,000*	*3,000,000*	87,002,500	87,002,500	-
X3	*7*	20,000-200,000[1)]	30,000-40,000[1)]	*7,000*	241,197 176,758 110,576 79,923 70,250	= (241,197 + 176,758 + 110,576 + 79,923 + 70,250) / 5 = 135,741	= 241,197 – 70,250 = 170,947

<u>Table 2.14</u> Example of data calculation (cont.)

Parameter	I	II	III	IV	V	VI	VII
	Plant A	Plant B	Plant C	Plant D	Flux		
					Flux	Flux Average	Range
X4	*400*	*1,000,000*	*2,000,000*	*600,000*	3,600,400	3,600,400	-
X5	*1,000,000*	60,000-130,000[1)]	*0.00*	*1,000,000*	1,051,900 1,030,357 505,266 503,626 358,352	= (1,051,900 + 1,030,357 + 505,266 + 503,626 + 358,352) / 5 = 689,900	= 1,051,900 – 358,352 = 693,549
X6	*20*	0-70[1)]	0-50[1)]	*0*	108 104 74 69 68	= (108 + 104 + 74 + 69 + 68) / 5 = 85	= 108 - 68 = 40

Note: Numbers in italic were provided by the industries but had been modified for confidentiality concern.

[1)] Uniform distribution was assumed.

Equation 2.15

Possible emission flux value

$$Flux_{R_A} = Flux_{min_A} + (Flux_{max_A} - Flux_{min_A}) \times RAND(\,)$$

Where

$Flux_{RA}$	:	Possible emissions flux of petrochemical plant A
$Flux_{minA}$	:	Possible minimum value of the emissions flux of petrochemical plant A
$Flux_{maxA}$	:	Possible maximum value of the emissions flux of petrochemical plant A
RAND( )	:	Random function in Microsoft Office Excel programme
A	:	Petrochemical plant

Employing Equation 2.14 and 2.15, the possible total emissions flux was:

Equation 2.16

Possible total emissions flux

$$\begin{aligned} Total\ Flux_R &= \sum_A Flux_{R_A} \\ &= \sum_A \left[Flux_{min_A} + \left(Flux_{max_A} - Flux_{min_A}\right) \times RAND(\,)\right] \end{aligned}$$

Where

$Total\ Flux_R$	:	Possible total emissions flux, tonne
$Flux_{R_A}$	:	Possible emissions flux of petrochemical plant A
$Flux_{min_A}$	:	Possible minimum value of the emissions flux of petrochemical plant A
$Flux_{max_A}$	:	Possible maximum value of the emissions flux of petrochemical plant A
RAND( )	:	Random function in Microsoft Office Excel programme
A	:	Petrochemical plant

Calculation using Equation 2.16 should be repeated in order to obtain the set of random total flux, which would be further used in the next steps. There are only 5 numbers of each parameter shown in Table 2.14 as example.

Column VI: Calculation of flux average

A set of total flux obtained from column V was used to estimate the average of total emissions flux as shown in Equation 2.17.

Equation 2.17

Flux average

$$Total\ Flux_{avg} = \frac{\sum_{i=1}^{n} Total\ Flux_{R_i}}{n}$$

Where

$Total\ Flux_{avg}$	:	Flux average of all petrochemical plants
$Total\ Flux_{R_i}$	:	Possible total emissions flux number i
i	:	Number of flux calculation
n	:	Total number of calculation repeat

Column VII: Calculation of the range of emissions flux

Using the range of the possible total flux in column V, the maximum and minimum values were identified and were used for calculating the range of the flux.

Equation 2.18

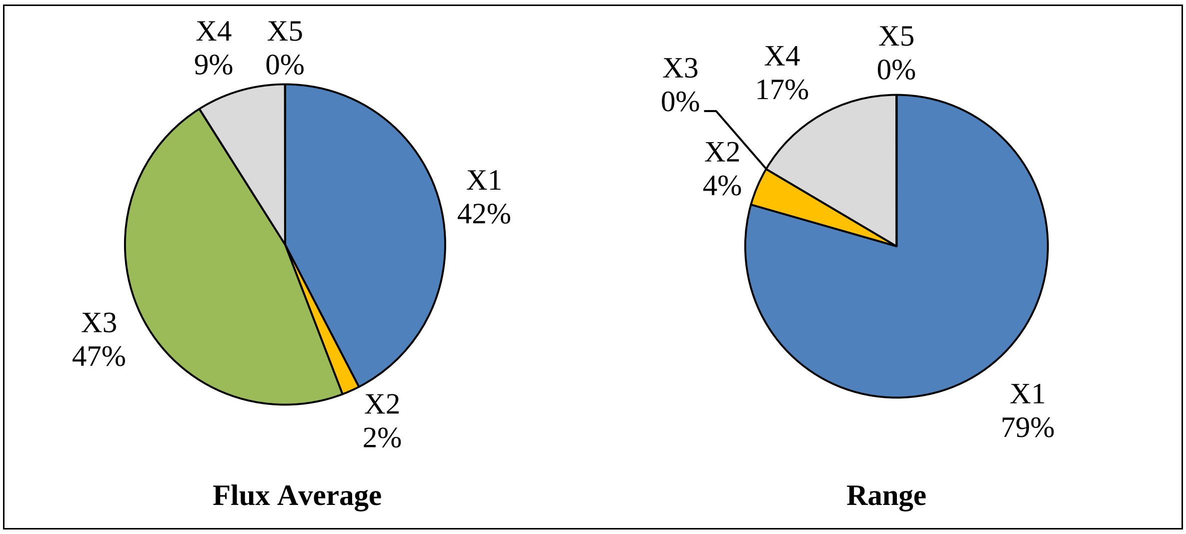
Range of emissions flux

$$Range\ of\ Flux = Total\ Flux_{max} + Total\ Flux_{min}$$

Where

Range of Flux	:	Range of total possible emissions flux
Total $Flux_{max}$	:	Maximum value of emissions flux
Total $Flux_{min}$	:	Minimum value of emissions flux

Next, a pie chart of the flux average (column VI) and the range of the flux (column VII) were plotted to see the major contributor (Figure 2.11).



<u>Figure 2.11</u> Example of total emission flux and range

According to Figure 2.12, it could be concluded that X1 was the main source of error as it had the widest range of the estimate and it dominated the total emissions flux. For this example, X3 also showed large contribution in total emissions flux, but its range was zero. Thus, should there be further data improvement; an action should be taken on X1 first.

In addition, as a number of assumptions were made, it was important to estimate the underlying error associated with such assumptions. Weight matrix approach was applied in this regard. Table 2.15 shows lists of assumptions inducing certain errors with their weight and potential error obtained from expert judgements. It was found that this set of assumptions contained about 5% of error.

Table 2.15 List of assumptions

Assumption	Weight[1)]	Error[1)]
Large error		
1. Seven percent of flaring loss	3	7.00%
2. Waste fuels burnt in petrochemical plants had same CO_2 emission intensity as that of natural gas.	3	10.00%
Moderate error		
3. Eighty percent of boiler efficiency	2	2.00%
4. Methane emissions from landfilling of solid organic waste were ignored.	2	2.00%
5. Fugitive emissions were ignore	2	1.00%
Small error		
6. Emissions arisen when materials were transport from one plant to adjacent plant.	1	1.00%

[1)] from expert judgement (PTIT, 2011)

2.8 DATA COMPILATION

The GHG estimates must be converted to carbon dioxide equivalent unit (CO_2eq) by multiplying the amount of GHG emissions with the corresponding global warming potential factors (GWP) for the 100 year time framed shown in Table 2.16.

Equation 2.19

Greenhouse gas emission i in carbon dioxide equivalent unit

$$E_{i(CO_2eq)} = E_i \times GWP_i$$

Where

$E_{i(CO_2eq)}$	:	Amount of greenhouse gas i in carbon dioxide equivalent unit, tonne CO_2eq
E_i	:	Amount of greenhouse gas i, tonne
GWP_i	:	Global warming potential, tonne CO_2eq/tonne GHG
i	:	Type of greenhouse gas

Table 2.16 Global warming potential of selected greenhouse gases

Greenhouse Gas	Global Warming Potential
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous oxide (N_2O)	310
HFC134a	1,300
Sulphur hexafluoride (SF_6)	23,900

Source: Forster, et al. 2007.

According to the concept that most of carbon emitted in the form of non-CO_2 species eventually oxidise to CO_2 in the atmosphere (IPCC, 2006a), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC) emissions could be convert to CO_2eq by using Equation 2.20 and 2.21 respectively.

Equation 2.20

Carbon monoxide in carbon dioxide equivalent unit

$$E_{CO(CO_2eq)} = E_{CO} \times {}^{44}/_{28}$$

Where

$E_{CO(CO_2eq)}$	:	Amount of carbon monoxide in carbon dioxide equivalent unit, tonne CO_2eq
E_{CO}	:	Amount of carbon monoxide, tonne

Equation 2.21

Non-methane volatile organic compounds in carbon dioxide equivalent unit

$$E_{NMVOC(CO_2eq)} = E_{NMVOC} \times Default \times {}^{44}/_{16}$$

Where

$E_{NMVOC(CO_2eq)}$		Amount of non-methane volatile organic compounds in carbon dioxide equivalent unit, tonne CO_2eq
E_{NMVOC}	:	Amount of non-methane volatile organic compounds emissions, tonne
Default	:	0.6

Finally, emissions of all petrochemical products were combined together to obtain the carbon budget of the entire petrochemical industries as shown in Equation 2.22

Equation 2.22

Total emissions of all petrochemical plants

$$Total\ E_{CO_2eq} = \sum_{A} Total\ E_{CO_2eq_A}$$

Where

$Total\ E_{CO_2eq}$	:	Total amount of emissions of all petrochemical plants, tonne CO_2eq
$Total\ E_{CO_2eq_A}$	:	Total amount of emissions of petrochemical plant A, tonne CO_2eq
A	:	Petrochemical plant

2.9 WORKSHEETS AND EXAMPLE

To aid understanding, an example of emission calculation is given in this report. It is noted that industrial actual data could not be displayed due to confidentiality reason. However, data provided in this example is presented in the same manner as founded in the real situation where only some information was reported.

The example demonstrates estimation of emissions from the production of a certain petrochemical product (X1). It is divided into 2 parts. Part 1 illustrates emissions estimation of one petrochemical plant (A); which covers data collection, calculation of emissions from relevant data, and data allocation. The result obtained from part 1 is further used in part 2 to estimate total emissions from the production of petrochemical product (X1) from various producers (A, B, C and D).

<u>Part 1: Estimation of emissions from petrochemical (X1) production of one producer</u>

2.9.1 Data collection and situation analysis

Given situation:

Petrochemical plant A produced petrochemical product X1 along with other byproducts, namely petrochemical X2, fuel gas and vent gas. They consumed natural gas as main fuel. They also consumed electricity and steam. However, it was not specified whether these energy were for petrochemical process or for onsite utility production. Carbon dioxide and other greenhouse gases were not reported. Important data and relevant information are shown in Table 2.17.

Table 2.17 Detail of petrochemical plant A

Item	Amount	Unit	Description
PRODUCTION			
Petrochemical X1	300	ktonne/y	Main product
Petrochemical X2	100	ktonne/y	Byproduct with market value
Fuel gas	50	ktonne/y	Byproduct exported to other plant as fuel
Vent gas	60	ktonne/y	Byproduct being recycled as process fuel
UTILITIES			
Fuel	5,500,000,000	MJ/y	Natural gas
Electricity	25,000	MWh/y	
Steam	800,000,000	MJ/y	Boiler efficiency is not known
AIR EMISSION			
Not reported			
WASTEWATER			Anaerobic deep lagoon
Wastewater flow rate	58	m^3/h	
COD	55,000	mg/m^3	
SOLID WASTE			
Not reported			

Procedure:

As air emission data were not reported, they must be calculated from relevant data that were consumed utilities. Then, emissions from wastewater were calculated from the given COD. Because petrochemical plant A produces several products at the same time, environmental loading must be allocated to each product. Finally, total emissions from the production of petrochemical product X1 could be estimated by combining every allocated emission parameter together.

2.9.2 Calculation of emissions

According to Equation 2.2, total emissions were a sum of airborne emissions, emissions from wastewater and emissions from solid waste.

<u>Equation 2.2</u>
Total emissions at the industrial plant
$E_{Total} = E_{Air} + E_{Wastewater} + E_{Solid\ waste}$

Where

E_{Total}	:	Total emissions, tonne CO_2eq
E_{Air}	:	Airborne emissions, tonne CO_2eq
$E_{Wastewater}$	:	Emissions from wastewater, tonne CO_2eq
$E_{Solid\ waste}$	:	Emissions from solid waste, tonne CO_2eq

Airborne emissions were a sum of emissions from energy sector and emissions from industrial processes. Emissions from energy sector were emissions associated with consumed fuel, electricity and steam. Emissions from industrial process were emissions from fuel combustion to provide thermal energy to production process, emissions from process vents, and emissions from flared waste gases during the production.

Because it was not specified whether the reported fuel was for energy sector or industrial process, it was assumed that the reported fuel was for industrial process. In addition, emissions from process vent must be measured directly. Thus, airborne emissions to be estimated are

- Emissions associated with consumed electricity
- Emissions associated with consumed steam
- Emissions from fuel combustion to provide thermal energy to production process
- Emissions from flared waste gases during the petrochemical production

Emissions from wastewater could be calculated from reported COD. Solid waste was not reported. Thus, it was omitted as suggested in section 2.1.2.1. Therefore, total emissions from the production of petrochemical product X1 could be estimated by using Equation 2.23.

<u>Equation 2.23</u>

Total emissions at the industrial plant

$$E_{Total} = E_{elec} + E_{steam} + E_{combustion} + E_{flare} + E_{Wastewater}$$

Where

E_{Total}	:	Total emissions
E_{elec}	:	Emissions associated with consumed electricity
E_{steam}	:	Emissions associated with consumed steam
$E_{combustion}$	:	Emissions from fuel combustion to provide thermal energy to production process
E_{flare}	:	Emissions from flared waste gases during petrochemical production
$E_{Wastewater}$	:	Emissions from wastewater

2.9.2.1 <u>Calculation of emissions associated with consumed electricity</u>

Step 1: Identify an amount of electricity consumed: 25,000 MWh/y.

Step 2: Select appropriate emission factor. Because specific emission factor was not given, a default country specific emission factors from Table 2.6 was employed. Global warming potential (GWP) of each greenhouse gas from Table 2.15 was employed to convert each GHG to CO_2eq unit. The result was shown in Table 2.17.

Table 2.18 Emission factor of average electricity grid in Thailand

Greenhouse Gas	Emission Factor (tonne/MWh)	GWP	Emission Factor (tonne CO_2eq/MWh)
CO_2	5.47×10^{-1}	1	5.47×10^{-1}
CH_4	2.77×10^{-3}	21	5.82×10^{-2}
N_2O	1.23×10^{-3}	310	3.81×10^{-1}
HFC134a	2.42×10^{-10}	1,300	3.15×10^{-7}
SF6	1.85×10^{-7}	23,900	4.42×10^{-3}
Total			9.91×10^{-1}

Step 3: Estimate emissions by multiplying the amount of electricity consumption by the selected emission factor as shown in Equation 2.5.

Equation 2.5

Greenhouse gas emissions associated with consumed electricity

$$Eelec_i = EC \times EF_i$$

Where:

$Eelec_i$	:	Emissions of greenhouse gas i associated with consumed electricity, tonne
EC	:	Electricity consumption, MWh
EF_i	:	Greenhouse gas i emission factor, tonne/MWh
i	:	Type of greenhouse gas

Thus, emissions associated with consumed electricity were:

$= (25{,}000\ \text{MWh/y}) \times (9.91 \times 10^{-1}\ \text{tonne}\ CO_2\text{eq/MWh})$

$= 24{,}775\ \text{tonne}\ CO_2\text{eq/y or}\ 2.48 \times 10^{4}\ \text{tonne}\ CO_2\text{eq/y}$

2.9.2.2 Calculation of emissions associated with consumed steam

Step 1: Identify amount of steam consumed: 800,000,000 MJ/y.

Step 2: Identify boiler efficiency (BF). Because BF was not given, a default value of 80% was employed.

Step 3: Identify type of fuel that is natural gas. According to Table 2.5, default emission factor of natural gas was 56.10 gCO_2eq/MJ.

Step 4: Calculate emissions by using Equation 2.7

Equation 2.7

Greenhouse gas emissions associated with consumed steam

$$Esteam_{ij} = \frac{SC}{BF} \times EF_{ij}$$

Where

$Esteam_{ij}$	:	Emissions of greenhouse gas i associated with consumed steam and with fuel j consumed in the steam generation, tonne
SC	:	Steam consumption, MJ
BF	:	Boiler efficiency
EF_{ij}	:	Greenhouse gas i emission factor of fuel j, tonne/MJ
i	:	Type of greenhouse gas
j	:	Type of fuel consumed in the steam generation

Thus, emissions associated with consumed steam were:

$$= \frac{(800{,}000{,}000\ MJ/y)}{(80\%)} \times (56.10\ \mathrm{gCO_2eq/MJ})$$

= 56,100,000,000 gCO_2eq/y or

= 56,100 tonne CO_2eq/y or 5.61×10^4 tonne CO_2eq/y

2.9.2.3 Emissions from fuel combustion to provide thermal energy to production process

Step 1: Identify an amount of fuel consumed: 5,500,000 MJ/y.

Step 2: Select an appropriate emission factor. As specific emission factor was not given; thus a default emission factor of natural gas of 56.10 gCO_2eq/MJ from Table 2.5 was employed.

Step 3: Calculate emissions by multiplying fuel consumption by the selected emission factor as shown in Equation 2.8

Equation 2.8

Greenhouse gas emissions from fuel or process byproduct combustion

$$Ecombustion_{Total} = \sum_j \sum_i \left(FCP_j \times EF_{ij}\right)$$

Where

$Ecombustion_{Total}$	:	Total emissions of greenhouse gas i from fuel or process byproduct j combusted to provide thermal energy to petrochemical production process, tonne
FCP_j	:	Consumption of fuel or process byproduct j in petrochemical production process, MJ
EF_{ij}	:	Greenhouse gas i emission factor of fuel or process byproduct j, tonne/MJ
i	:	Type of greenhouse gas
j	:	Type of fuel or process byproduct

Thus, emissions from fuel combustion to provide thermal energy to production process were:

$= (5{,}500{,}000{,}000 \text{ MJ/y}) \times (56.10 \text{ g}CO_2\text{eq/MJ})$
$= 308{,}550{,}000{,}000 \text{ g}CO_2\text{eq/y}$ or
$= 308{,}550 \text{ tonne } CO_2\text{eq/y}$ or $3.09 \times 10^5 \text{ tonne } CO_2\text{eq/y}$

2.9.2.4 Emissions from flared waste gases during the petrochemical production

Since there was not enough data to calculate emissions from specific flared waste gases, it was assumed that it was 7% of total emissions from industrial process.

This implied that emissions from industrial process (E_{Ind}) were:

$$\begin{aligned} E_{Ind} &= E_{combustion} + 7\% \, (E_{Ind}) \\ E_{Ind} - 7\% \, (E_{Ind}) &= E_{combustion} \\ (1 - 0.07)E_{Ind} &= E_{combustion} \\ (0.93)E_{Ind} &= E_{combustion} \end{aligned}$$

Or it can be written as:

Equation 2.24

Total emissions at the industrial plant

$$E_{Ind} = \frac{E_{combustion}}{0.93}$$

Where

E_{Ind}	:	Emissions from industrial process
$E_{combustion}$	:	Emissions from fuel combustion to provide thermal energy to production process

2.9.2.5 Emissions from wastewater

Step 1: Estimate total organically degradable carbon in wastewater by using Equation 2.11.

Equation 2.11

Organically degradable material in industrial wastewater

$$TOW = W \times COD$$

Where:

TOW	:	Total organically degradable material in wastewater from the industrial production, tonne COD
W	:	Wastewater generated, m^3
COD	:	Chemical oxygen demand, tonne COD/m^3

Total organically degradable carbon in wastewater was:

$$= (58\ m^3/h) \times (55{,}000\ mg\ COD/m^3)$$
$$= 3{,}190{,}000\ mg\ COD/h$$

It was assumed that this petrochemical plant operated 24 hour per day and 365 days per year.

Thus, total organically degradable carbon in wastewater was:

$$= (3{,}190{,}000\ mg\ COD/h) \times (24\ h/day) \times (365\ days/y)$$
$$= 27{,}944{,}400{,}000\ mg\ COD/y$$
$$= 27{,}944.4\ kg\ COD/y$$

Step 2: Identify emission factor. Because the specific emissions factor was not given, it was estimated by using Equation 2.12.

<u>Equation 2.12</u>

Emission factor for industrial wastewater

$$EF_w = B_o \times MCF_w$$

Where

EF_w	:	Emission factor for each treatment/discharge pathway or system, tonne CH_4/tonne COD
B_o	:	Maximum methane (CH_4) producing capacity, tonne CH_4/tonne COD
MCF_w	:	Methane correction factor
w	:	Each treatment/discharge pathway or system

A default value of maximum methane producing capacity or B_o was employed, which was 0.25 kg CH_4/kg COD. Methane correction factor or MCF of anaerobic deep lagoon was 0.8 (Table 2.10).

Thus, emission factor was:

$$= (0.25 \text{ kg } CH_4/\text{kg COD}) \times (0.8)$$
$$= 0.20 \text{ kg } CH_4/\text{kg COD}$$

Step 3: Estimate methane (CH_4) emissions by using Equation 2.13.

<u>Equation 2.13</u>

Total methane (CH_4) emissions from industrial wastewater

$$Ew_{CH_4} = (TOW - S)EF_w - R$$

Where

Ew_{CH_4}	:	Total methane (CH_4) emissions from industrial wastewater, tonne CH_4
TOW	:	Total organically degradable material in wastewater, tonne COD
S	:	Organic component removed as sludge, tonne COD

EF_w	:	Emission factor for treatment/discharge pathway or system(s) used, tonne CH_4/tonne COD
R	:	Amount of CH_4 recovered in inventory year, tonne CH_4

As organic component removed as sludge (S) and amount of CH_4 recovered were not reported, both of them were assumed to be zero. Thus, methane (CH_4) emissions from wastewater were:

$$= (27{,}944.4 \text{ kg COD/y}) \times (0.20 \text{ kg } CH_4\text{/kg COD})$$

$$= 5{,}588.88 \text{ kg } CH_4\text{/y}$$

The value of GWP of CH_4 from Table 2.15 was employed to convert CH_4 emissions into the unit of CO_2eq. Thus, emissions from wastewater were:

$$= (5{,}588.88 \text{ kg } CH_4\text{/y}) \times 21$$

$$= 117{,}366.48 \text{ kg } CO_2\text{eq/y or}$$

$$= 0.12 \text{ tonne } CO_2\text{eq/y or}$$

2.9.3 Data allocation

Because petrochemical plant A produced several products at the same time, environmental loading must be allocated to each product by using mass allocation.

Step 1: Identify product to be allocated with environmental loading by using definitions given in Table 2.2. The result is shown in Table 2.19.

Table 2.19 List of products for environmental loading allocation

Product	Description	Code	To Be Allocated with Environmental Loading
Petrochemical X1	Main product	A1	Yes
Petrochemical X2	Byproduct with market value	A2	Yes
Fuel gas	Byproduct exported to other plant as fuel	A3	Yes
Vent gas	Byproduct being recycled as process fuel	N1	No

Step 2: Calculate production ratio of product listed for environmental loading calculation. The result is shown in Table 2.20.

Table 2.20 Production ratio of each product

Product	Code	Amount (ktonne/y)	Production Ratio
Petrochemical X1	A1	300	$= \frac{300}{300+100+50} = 0.67$
Petrochemical X2	A2	100	$= \frac{100}{300+100+50} = 0.22$
Fuel gas	A3	50	$= \frac{50}{300+100+50} = 0.11$
Vent gas	N1	60	

Step 3: Allocate environmental loading to each product by multiplying the amount of environmental loading by production ratio of each product. The result is shown in Table 2.21.

Table 2.21 Allocation worksheet

Items	Amount	Unit	Main Product		Byproduct		Off-Spec Product	Process Waste	
			A1	N1	A2	A3	A4	A5	A6
			X1	Vent Gas	X2	Fuel gas			
PRODUCTION									
Production rate		ktonne/y	300	60	100	50			
Production ratio		-	0.67		0.22	0.11			
AIR EMISSIONS									
Eelec	2.48×10^4	tonne CO_2eq/y	$= 2.48\times10^4 \times0.67 = 1.66\times10^4$		$= 2.48\times10^4 \times0.22 = 5.45\times10^3$	$= 2.48\times10^4 \times0.11 = 2.73\times10^3$			
Esteam	5.61×10^4	tonne CO_2eq/y	$= 5.61\times10^4 \times0.67 = 3.76\times10^4$		$= 5.61\times10^4 \times0.22 = 1.23\times10^4$	$= 5.61\times10^4 \times0.11 = 6.17\times10^3$			
Ecombustion	3.09×10^5	tonne CO_2eq/y	$= 3.09\times10^5 \times0.67 = 2.07\times10^5$		$= 3.09\times10^5 \times0.22 = 6.79\times10^4$	$= 3.09\times10^5 \times0.11 = 3.39\times10^4$			
WASTEWATER									
Ewastewater	0.12	tonne CO_2eq/y	$= 0.12\times0.67 = 0.08\times10^{-2}$		$= 0.12\times0.22 = 2.64\times10^{-2}$	$= 0.12\times0.11 = 1.32\times10^{-2}$			

According to Equation 2.23 – 2.24 and Table 2.21, total emissions from the production of petrochemical product X1 of petrochemical plant A were:

$$
\begin{aligned}
E_{Total} &= E_{elec} + E_{steam} + E_{combustion} + E_{flare} + E_{Wastewater} \\
&= E_{elec} + E_{steam} + E_{ind} + E_{Wastewater} \\
&= E_{elec} + E_{steam} + \frac{E_{combustion}}{0.93} + E_{Wastewater} \\
&= (1.66 \times 10^4) + (3.76 \times 10^4) + \frac{(2.07 \times 10^5)}{0.93} + (0.08 \times 10^{-2}) \\
&= 2.76 \times 10^5 \text{ tonne } CO_2\text{eq/y or } 276{,}475 \text{ tonne } CO_2\text{eq/y}
\end{aligned}
$$

<u>Part 2: Estimation of emissions from petrochemical (X1) production of all producers</u>

2.9.4 Data collection and situation analysis

Given situation:

Petrochemical product X1 was produced from 4 producers, namely petrochemical plant A, B, C and D. Emissions of petrochemical plant A (from part 1), C and D were identified, while emissions of petrochemical plant B were missing. Production rate of each plant was given in Table 2.22.

<u>Table 2.22</u> Petrochemical product X1 production of all petrochemical plants

Item	Petrochemical Plant			
	A	B	C	D
Production (ktonne/y)	300	270	400	150
Emissions (tonne CO2eq/y)	276,475	Unknown	350,196	294,832

Procedure:

Emissions of petrochemical plant B must be estimated by using data of other producers. Then, sensitivity analysis and data selection tiers were employed to select the most appropriate estimates. Finally, total emissions flux and a range of error could be calculated.

2.9.5 Uncertainty analysis

Step 1: Plot a graph between production and emissions of plant A, C and D are plotted as suggested by a decision tree in Figure 2.6. The result is shown in Figure 2.12.

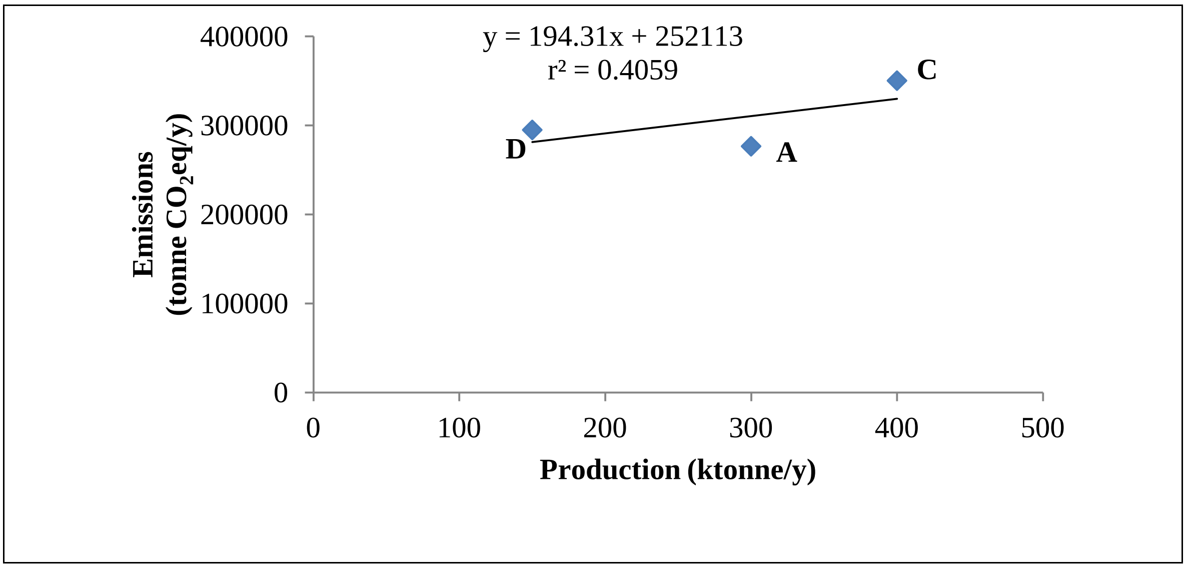


Figure 2.12 Correlation of emissions and production of petrochemical plant A, C and D with 1 trendline

Step 2: Consider the value of the square of correlation coefficient (r^2). It was found that the r^2 value was low, which represented a poor correlation of data.

Step 3: Separate trendlines into 3 lines (Figure 2.13).

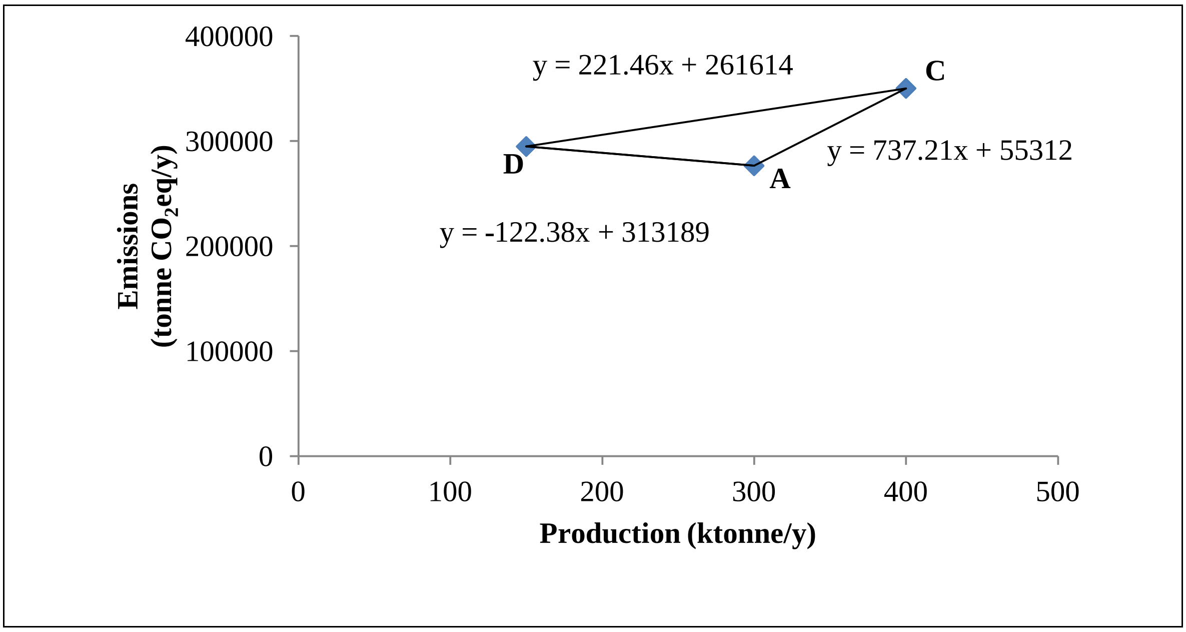


Figure 2.13 **Correlation of emissions and production of petrochemical plant A, C and D with 3 trendlines**

Step 3: Estimate emissions of plant B by using the corresponding correlation equations. The results are shown in Table 2.23.

Table 2.23 **Petrochemical product X1 production of all petrochemical plants**

<table>
<tr><th rowspan="2">Item</th><th colspan="4">Petrochemical Plant</th><th rowspan="2">Correlation Equation</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td>Production (ktonne/y)</td><td>300</td><td>270</td><td>400</td><td>150</td><td></td></tr>
<tr><td rowspan="3">Emissions (tonne CO_2eq/y)</td><td>276,475</td><td>Case a) 311,008</td><td>350,196</td><td>294,832</td><td>y= 301.46x + 229614</td></tr>
<tr><td></td><td>Case b) 254,359</td><td></td><td></td><td>y= 737.21x + 55312</td></tr>
<tr><td></td><td>Case c) 280,146</td><td></td><td></td><td>y= -122.38x + 313189</td></tr>
</table>

Step 4: Select the most appropriate estimates by using data selection tier as suggested in section 2.7.2. In this regard, estimate of case a) and case b) were selected while estimate of case c) was not. This was because case c) was a result of correlation equation with negative slope.

Step 5: Calculate total emission flux and a range of error by using Equation 2.16 – 2.18. The result is shown in Table 2.24.

Therefore, total emissions of the production of petrochemical product X1 from all producers were:

$$= \quad 1{,}207{,}026 \pm 51{,}352 \text{ tonne } CO_2\text{eq/y or}$$

$$= \quad 1{,}207 \pm 51.35 \text{ ktonne } CO_2\text{eq/y or}$$

$$= \quad 1{,}207 \text{ ktonne } CO_2\text{eq/y } (\pm 4.25\%)$$

And emission intensity was:

$$= \quad \frac{1{,}207 \pm 51.35}{(300 + 270 + 400 + 150)} \quad \frac{\text{ktonne CO2eq}}{\text{ktonne production}}$$

$$= \quad 1.0777 \pm 0.0458 \text{ ktonne } CO_2\text{eq/ktonne production or}$$

$$= \quad 1.0777 \text{ ktonne } CO_2\text{eq/ktonne production } (\pm 4.25\%)$$

Table 2.24 **Example of calculation of total emission flux and a range of error**

Parameter	I	II	III	IV	V	VI	VII
	Plant A	Plant B	Plant C	Plant D	Flux		
					Flux	Flux Average	Range
Emissions (tonne CO_2eq/y)	276,475	254,359 - 311,008	350,196	294,832	1,178,116 1,200,919 1,201,316 1,225,309 1,229,468	= (1,178,116 + 1,200,919 + 1,201,316 + 1,225,309 + 1,229,468) / 5 = 1,207,026	= 1,229,468 - 1,178,116 = 51,352

CHAPTER 3

CARBON BUDGET OF THE PETROCHEMICAL INDUSTRIES IN THAILAND

CHAPTER 3

CARBON BUDGET OF THE PETROCHEMICAL INDUSTRIES IN THAILAND

3.1 SOURCE AND NATURE OF DATA

Main data required for the development of carbon budget were emissions of carbon dioxide and other greenhouse gases (GHGs) of the petrochemical industries including their production capacities and utility consumption. Nevertheless, emissions and utility consumption data were considered as ones of highly confidential data of industries. Accessing to these data was limited to the relevant company personnel. This study, therefore, employed data from secondary source that was the environmental impact assessment (EIA) report the factories submitted to the government agency. The data obtained was for the year 2008.

Common emission parameters reported in the EIA report were: total suspended particulates (TSP); nitrogen oxides (NO_x); sulphur oxides (SO_x); and heavy metal such as mercury (Hg) and lead (Pb). Emissions of GHG were only reported on a voluntary basis. Only some plants reported GHG emissions, for example, carbon dioxide (CO_2) and non-methane volatile organic compound (NMVOC). Other factors required for emission calculation such as utility consumption were only reported rarely. Thus, it was necessary to denote the level of data completeness which reflected quality and reliability of the developed carbon budget. The level of data completeness in this study comprised of one digit (1-5) referring to the obtained data and one alphabet (A-B) referring the additional calculation for the missing data. The criteria for assigning quality criteria are listed in Table 3.1.

Table 3.1 Criteria utilised for assessing the level of data completeness

Level	Description
1	The obtained data comprised of: - production capacity - wastewater parameter from industrial processing
2	The obtained data comprised of - production capacity - utility consumption
3	The obtained data comprised of - production capacity - air emission from industrial processing - wastewater from industrial processing
4	The obtained data comprised of - production capacity - utility consumption - air emission from industrial processing - wastewater from industrial processing
5	The obtained data comprised of - production capacity - utility consumption - source of utility - air emission from industrial processing - wastewater parameter from industrial processing
A	There was no missing data and thus no requirement for additional estimation. This might be because either there was only one producer of the interested product or all the data of the particular parameter were obtained.
B	Calculation was required for the missing data.

From Table 3.1, level 5 gave the most accurate result as all of the necessary data were obtained. Both emissions from energy sector and industrial processing could be estimated, whereas level 2 implied emissions from energy sector and level 3 gave emissions from industrial processing only. Level 4 also gave emissions of both energy sector and industrial processing but as source of utilities was not specific it was not possible to classify direct and indirect emission. Level 1 gave the least accurate inventory as there was only wastewater parameter obtained, which normally had a small contribution in the carbon budget, hence led to the underestimation of the carbon budget.

There were two main points of concern in the development of the carbon budget in this study.

3.1.1 Incompleteness of data:

Despite the attempt to access the data as complete as possible, there were many cases where the required data were not available. It should also be noted that the developed carbon budget might contain a range of uncertainties, which should be further assessed to prioritise future inventory improvement.

3.1.2 Confidentiality of data:

The data must be treated confidentially in order to avoid the release of proprietary and sensitive data from any one company or industry. Data of individual product and/or data of individual company must not be shown in the report. Only the aggregated data of the industries can be reported.

3.2 CARBON BUDGET OF THE PETROCHEMICAL INDUSTRIES IN THAILAND

The carbon budget was developed from the data of the upstream, intermediate and downstream petrochemical industries and the plastics and derivative industry. Effort was made to collect data of many products as possible. The products of which their data were obtained for this study together with their production capacity in the percentage of the national capacity and the level of data completeness are listed in Table 3.2.

Table 3.2 **List of products used in the development of carbon budget for Thai petrochemical industries**

Product	Production Capacity of Acquired Data Comparing to National Capacity (%)	Level of Data Completeness
Upstream petrochemical industry		
1. Benzene	100	3B
2. Butadiene	100	2B
3. Ethylene	100	2A
4. Mixed C4	100	2B
5. Benzene	100	3B
6. Butadiene	100	2B
7. Ethylene	100	2A
8. Mixed C4	100	2B
9. Mixed xylene	47	2B
10. Propylene	90	2A
11. P-xylene	100	3B
12. Toluene	41	2A
Intermediate petrochemical industry		
1. Acetone	100	2A
2. Bisphenol A	100	4A
3. Di-ethylene glycol (DEG)	100	2A
4. Ethylene oxide	100	2A
5. Mono-ethylene glycol (MEG)	100	2A
6. Phenol	100	2A
7. Phthalic anhydride (PA)	100	2A
8. Poly-ethylene glycol (PEG)	100	2A
9. Polyols	NR	2B
10. Purified terephthalic acid (PTA)	100	2B
11. Styrene monomer (SM)	100	3A
12. Tri-ethylene glycol (TEG)	100	2A

Table 3.2 List of products used in the development of carbon budget for Thai petrochemical industries (cont.)

Product	Production Capacity of Acquired Data Comparing to National Capacity (%)	Level of Data Completeness
Downstream petrochemical industry		
1. Acrylonitrile butadiene styrene (ABS)	100	2B
2. Advance Superabsorbent Monomer	NR	5A
3. Butyl methacrylate (BMA)	100	5A
4. Polybutadiene rubber (BR)	100	2B
5. Compound plastic	NR	2A
6. Dioctyl phthalate (DOP)	NR	2A
7. High density polyethylene (HDPE)	100	2B
8. Low density polyethylene (LDPE)	100	2B
9. Liquid epoxy	NR	2A
10. Linear low density polyethylene (LLDPE)	100	3A
11. Melamine	NR	2A
12. Methyl methacrylate (MMA)	100	5A
13. Multifunctional epoxy resin	NR	2A
14. Nylon 6	NR	1A
15. Polycarbonate (PC)	100	2A
16. Polyethylene terephthalate (PET)	NR	3A
17. Polyethylene terephthalate (PET) -Bottle grade	NR	1A
18. Polyethylene terephthalate (PET) -Fibre	NR	4B
19. Polyacetal	100	5A
20. Polypropylene (PP)	100	2B
21. Polystyrene (PS)	88	3B
22. Polyuretane (PU)	NR	1B
23. Styrene acrylonitrile (SAN)	NR	3A
24. Solid epoxy	NR	2A
25. Solution epoxy	NR	2A
26. Specialty epoxy	NR	2A
27. Vinyl cis polybutadiene rubber (VCR)	NR	2A

Table 3.2 **List of products used in the development of carbon budget for Thai petrochemical industries (cont.)**

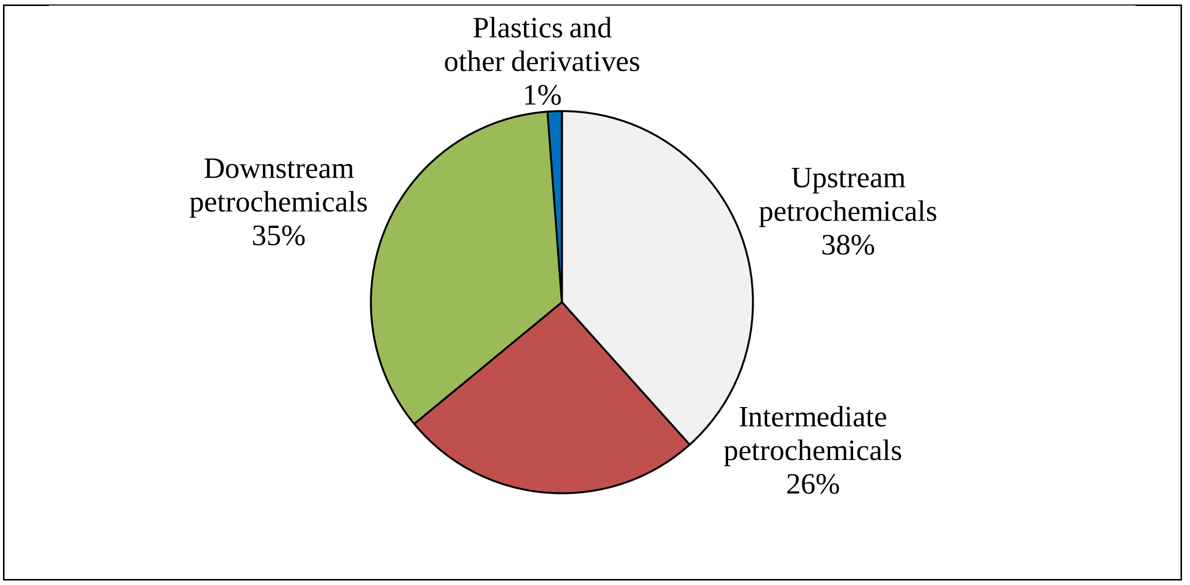
Product	Production Capacity of Acquired Data Comparing to National Capacity (%)	Level of Data Completeness
Plastic and other derivatives industry		
1. Blown film for producing packaging bag	NR	2A
2. Draw textured yarn	NR	3A
3. Nitrile latex	NR	2A
4. Partially-oriented yarn	NR	3A
5. Plastic resin for pipe	NR	2A

Note. NR means national production capacity was not reported.

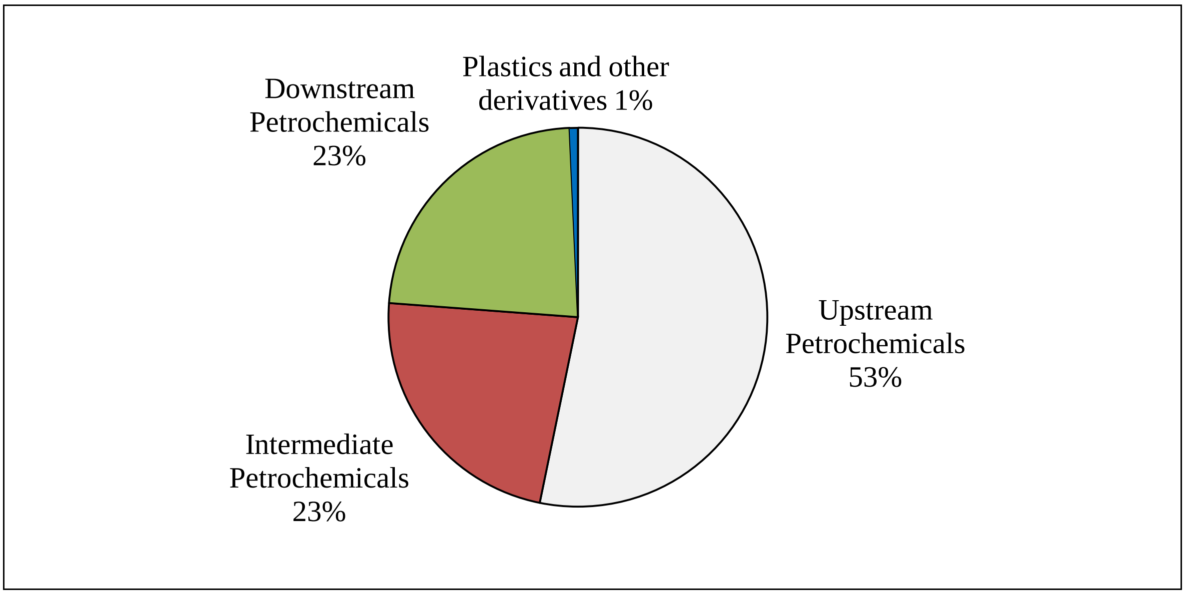
The total carbon budget of the petrochemical industries in Thailand for the year 2008 was 10,966 ktonnes CO_2eq (±10%) and their emission intensity was 0.6346 ktonnes CO_2eq per ktonne of production (±10%). Average emission intensity of each industrial phase is shown in Table 3.3. Production share and emission share of each industrial phase are shown in Figure 3.1 and Figure 3.2 respectively. Due to confidentiality concern, emission intensity of each product could not be displayed in this report.

Table 3.3 **Average emission intensity of each industrial phase**

Industrial phase	Average Emission Intensity (ktonnes CO_2eq / ktonnes$_{production}$)
Upstream petrochemical	0.8783 ± 0.0873
Intermediate petrochemical	0.5739 ± 0.0547
Downstream petrochemical	0.4195 ± 0.0014
Plastics and other derivatives	0.3698 ± 0.0000



<u>Figure 3.1</u> Production share of each industrial phase, 2008



<u>Figure 3.2</u> Carbon emissions by industrial phase, 2008

The upstream petrochemical industry emitted the largest share of carbon emission with about 53% of the total followed by the intermediate and downstream petrochemical industries, which had the same emission share of 23%. The plastics and other derivative industry had only 1 % of emissions share. There were two factors that control this outcome: production capacity and emission intensity. The higher production capacity and the higher the emission intensity then the higher the resulting emissions. For the intermediate petrochemical industry, although the production share was less than that of the downstream petrochemical industry, but as their average emission intensity were higher than that of the downstream petrochemical industry, the emission shares of these two industries were finally equal.

When particular products were considered (Table 3.4), the top five emissions contributors were ethylene, PTA, propylene, p-xylene, and HDPE, which altogether constituted more than 60 % of the total emission. Their emissions dominated by their productions which constituted about 50 % of the total production. Their emission intensity, however, ranked at 11th, 26th, 10th, 13th, and 16th respectively. Five products with the highest emission intensity were MMA, BMA, advanced superabsorbent monomer, BR, and VCR, however, due to their small production share (<1.5%) their emissions share amounted to only about 5 % of total emissions.

Table 3.4 Production and emission contribution of each product

Product	Number of Plants	Overall Production Contribution	Emission Contribution	
			Overall	Within the Same Industrial Phase
Upstream petrochemical industry				
1. Benzene	5	4.8881%	6.4452%	12.1651%
2. Butadiene	2	1.1299%	1.1452%	2.1615%
3. Ethylene	4	13.7571%	22.0704%	41.6573%
4. Mixed C4	3	1.3586%	2.2320%	4.2458%
5. Mixed xylene	3	1.7760%	0.4064%	0.7671%
6. Propylene	4	6.5436%	10.5417%	19.8971%
7. P-xylene	3	7.1049%	8.9260%	15.4551%
8. Toluene	3	1.8052%	1.9344%	3.6511%
Intermediate petrochemical industry				
1. Acetone	1	0.7157%	0.7393%	3.2851%
2. Bisphenol A	1	1.3020%	1.5701%	6.9772%
3. Di-ethylene glycol (DEG)	1	0.4919%	0.3503%	1.5568%
4. Ethylene oxide	1	0.1207%	0.0860%	0.3822%
5. Mono-ethylene glycol (MEG)	1	1.2621%	0.8989%	3.9944%
6. Phenol	1	0.0031%	0.0022%	0.0099%
7. Phthalic anhydride (PA)	1	0.0055%	0.0040%	0.0176%

Table 3.4 Production and emission contribution of each product (cont.)

Product	Number of Plants	Overall Production Contribution	Emission Contribution	
			Overall	Within the Same Industrial Phase
Intermediate petrochemical industry (cont.)				
8. Poly-ethylene glycol (PEG)	1	1.1573%	1.1954%	5.3122%
9. Polyols	2	0.2893%	0.1373%	0.6103%
10. Styrene monomer (SM)	2	2.0784%	1.0500%	4.6659%
11. Purified terephthalic acid (PTA)	3	15.5082%	11.5618%	50.4992%
12. Tri-ethylene glycol (TEG)	1	2.7376%	5.1057%	22.6891%
Downstream petrochemical industry				
1. Acrylonitrile butadiene styrene (ABS)	1	1.1573%	0.0032%	0.0141%
2. Advance Superabsorbent Monomer	1	0.1447%	0.5729%	2.5001%
3. Butyl methacrylate (BMA)	1	0.0781%	0.4040%	1.7630%
4. Polybutadiene rubber (BR)	2	0.3038%	1.1476%	5.0084%
5. Compound plastic	2	0.4874%	0.4405%	1.9224%
6. Dioctyl phthalate (DOP)	1	0.2083%	0.0989%	0.4316%
7. High density polyethylene (HDPE)	6	6.8050%	8.4876%	37.0420%
8. Low density polyethylene (LDPE)	2	1.4929%	1.7480%	7.6287%
9. Liquid epoxy	1	0.1871%	0.0018%	0.0080%
10. Linear low density polyethylene (LLDPE)	2	2.1283%	0.2086%	0.9104%
11. Melamine	1	0.0556%	0.0580%	0.2531%
12. Methyl methacrylate (MMA)	1	0.5492%	2.8387%	12.3887%
13. Multifunctional epoxy resin	1	0.0060%	0.0001%	0.0003%
14. Nylon 6	2	0.6365%	0.0114%	0.0500%
15. Polycarbonate (PC)	2	2.3725%	3.0807%	13.4451%
16. Polyethylene terephthalate (PET)	1	0.7604%	0.0002%	0.0011%

Table 3.4 Production and emission contribution of each product (cont.)

Product	Number of Plants	Overall Production Contribution	Emission Contribution	
			Overall	Within the Same Industrial Phase
Downstream petrochemical industry (cont.)				
17. Polyethylene terephthalate (PET) -Bottle grade	4	1.8250%	1.0909%	4.7612%
18. Polyethylene terephthalate (PET) –Fibre	10	4.8694%	0.7328%	3.1979%
19. Polyacetal	1	0.3183%	0.5060%	2.2082%
20. Polypropylene (PP)	3	7.2333%	0.4025%	1.7564%
21. Polystyrene (PS)	4	2.0266%	0.3421%	1.5507%
22. Polyuretane (PU)	2	0.4061%	0.0039%	0.0170%
23. Styrene acrylonitrile (SAN)	1	0.3472%	0.0077%	0.0337%
24. Solid epoxy	1	0.1017%	0.0010%	0.0044%
25. Solution epoxy	1	0.0381%	0.0004%	0.0016%
26. Specialty epoxy	1	0.0368%	0.0004%	0.0016%
27. Vinyl cis polybutadiene rubber (VCR)	1	0.1881%	0.7104%	3.1004%
Plastic and other derivatives industry				
1. Blown film for producing packaging bag	1	0.0000%	0.0001%	0.0102%
2. Draw textured yarn	1	0.3686%	0.0546%	7.8187%
3. Nitrile latex	1	0.6944%	0.6223%	89.1948%
4. Partially-oriented yarn	1	0.1377%	0.0204%	2.9213%
5. Plastic resin for pipe	1	0.0002%	0.0004%	0.0551%

The carbon budget was also disaggregated for the energy sector and industrial process as shown in Figure 3.3. The definition of the energy sector and the industrial process are given in Box 3.1.

Box 3.1

Definition of energy sector and industrial process

Emissions from energy sector involves emissions from the generation of both onsite and procured utilities

Emissions from industrial process involves emissions from industrial processing, emissions from fuel used in the process, process vent, and flared emissions.

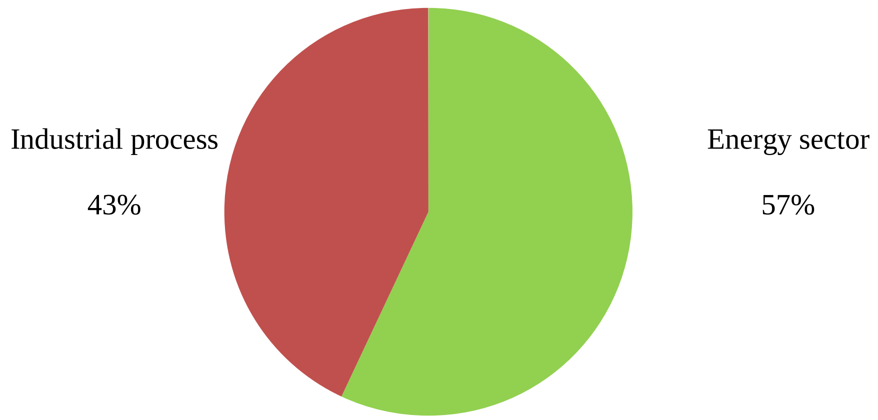


Figure 3.3 Emissions share of energy sector and industrial process

Figure 3.3 suggested that emissions associated with consumed utilities were higher than emissions caused by industrial processing. Thus, if the petrochemical industries need to mitigate their emissions, it could be achieved by increasing the energy efficiency at their onsite utility generation and/or seeking for alternative utility suppliers with higher energy efficiency production.

In view of direct and indirect emissions of which the definition was given in Box 2.1 of Chapter 2, the direct emissions of the petrochemical industries were higher than the indirect emissions (Figure 3.4). This was sensible as most of major plants which dominated the production share had their own onsite utility generation units. Emissions at their plants, which included emissions from the generation of utilities and the industrial processing, was therefore higher than the indirect emissions which mostly involved procured utilities only. Taking into account the result of energy and industrial sector analysis, if the petrochemical industries would like to reduce their emissions, emissions associated with the onsite utility generation could be the place to start.

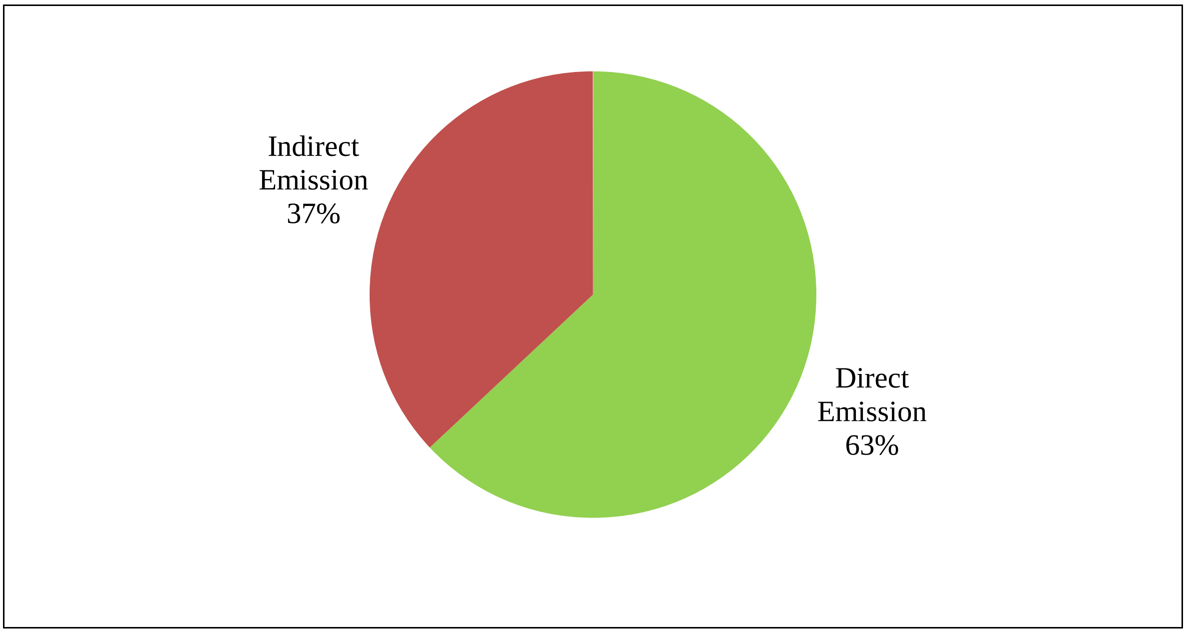


Figure 3.4 Direct and indirect emissions of Thai petrochemical industries

From the uncertainty analysis, there were 4 products considered as major sources of error of the total carbon budget: p-xylene, mixed C4, polystyrene (PS) and purified terephthalic acid (PTA). Table 3.5 shows error of these products and their emission contribution.

Table 3.5 Major sources of error

Product	Error	Emission Contribution
P-xylene	69%	8.93%
Mixed C4	23%	2.23%
Polystyrene (PS)	20%	0.34%
Purified terephthalic acid (PTA)	18%	11.56%

The error was mainly due to the incompleteness of the obtained data. In order to improve an accuracy of the total carbon budget in the future, it was advised to acquire higher quality data of these 4 products. However, should there be constraint concerning acquiring data e.g. resource limitation, it was suggested to prioritise the improvement by considering emission share of each product. From Table 3.5, p-xylene and PTA had emission share of 8.93% and 11.56% respectively. Amendment to their data would result in a noticeable change in the total carbon budget. On the other hand, mixed C4 and PTA had only 2.23% and 0.34% emission share respectively. A change in their data would not make an obvious change in the total carbon budget. Therefore, acquiring data of p-xylene and PTA would take priority over acquiring data of mixed C4 and PS.

3.3 COMPARISON OF THE CARBON BUDGET OF THE PETROCHEMICAL INDUSTRIES IN THAILAND AND THE PERTINENT INDUSTRIES IN OTHER COUNTRIES

In accordance with the United Nations Framework Convention on Climate Change (UNFCC), the participated countries, so-called Annex I parties, annually submitted their national inventories of anthropogenic GHG emissions to the secretariat of the Convention. As data of the petrochemical industries were not available, data employed in this study was GHG emissions of the chemical industries of the year 2008 (Table 3.6). Two important matters should be noted.

1) The data being compared were not precisely from the same industries.
2) The data obtained from UNFCCC were also incomplete and thus contained uncertainty. For example, there were some cases that the production capacity of the entire chemical industries was not reported, which led to the incorrect emission intensity.

Table 3.6 Greenhouse gas emission of chemical industries of the year 2008

Country	Production Capacity (ktonne/y)	Emission Intensity (ktonne CO_{2eq}/$ktonne_{Production}$)
Germany	90,533	0.2517
United States of America	126,049	0.3399
New Zealand	2,212	0.5302
Thailand[a]	17,281	0.6346
Russia	38,715	0.8389
Japan	51,379	1.1230
France	20,004	1.2383
Austria	1,614	1.4401

Table 3.6 Greenhouse gas emission of chemical industries of the year 2008 (cont.)

Country	Production Capacity (ktonne/y)	Emission Intensity (ktonne CO_{2eq}/ktonne$_{Production}$)
Austria	1,614	1.4401
United Kingdom	1,966	2.8161
Canada	5,112	3.3304
Belgium	3,278	3.3314

[a]The data is for the petrochemical industries of the year 2008.

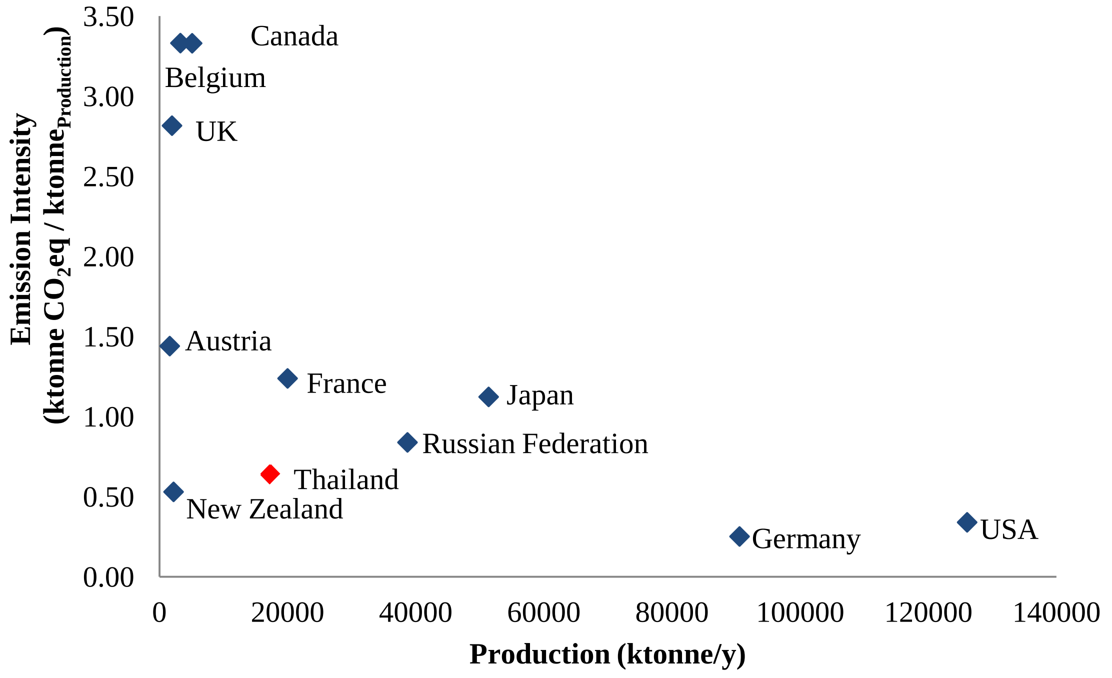
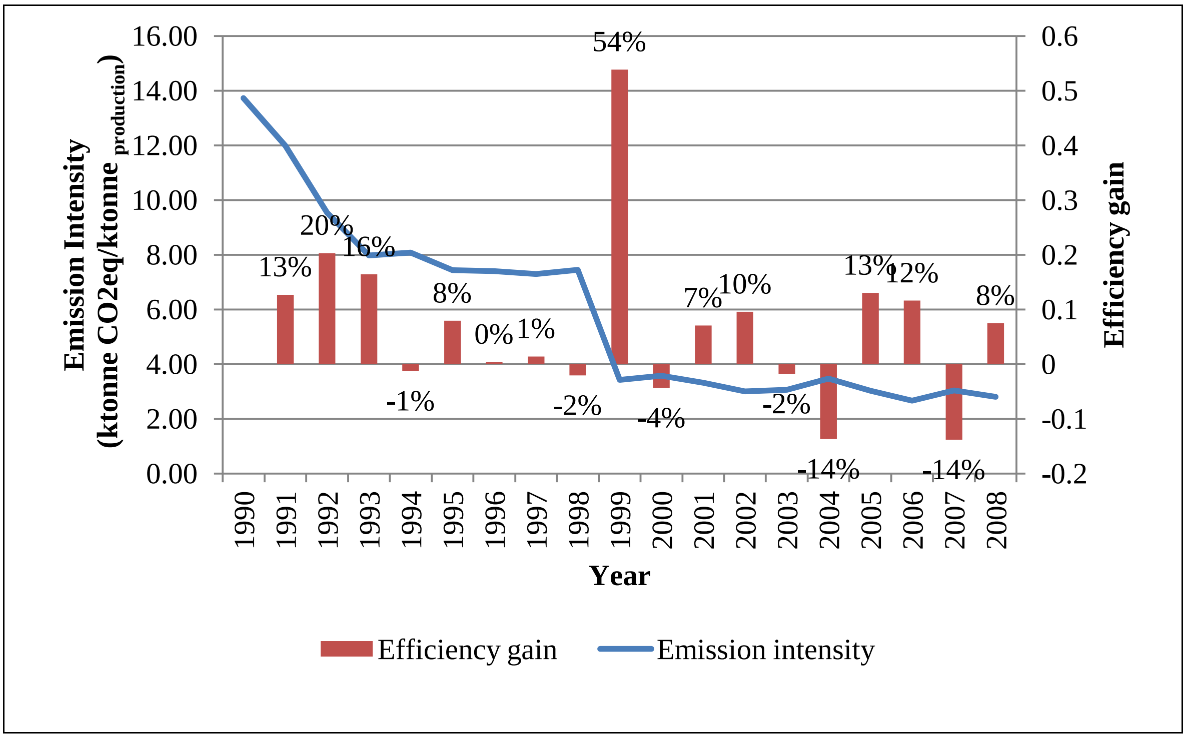


Figure 3.5 Emission intensity of each country compared to its total production

According to Table 3.6 and Figure 3.5, Germany had the best carbon emission performance with the emission intensity of 0.2517, followed by the United States of America and New Zealand with the emission intensity of 0.3399, and 0.5302, respectively. Thailand held the fourth rank with the emission intensity of 0.6346. This showed that the petrochemical industries in Thailand had a creditably low level of carbon emission. In addition, should the industries need to improve their carbon emission management, the practice of these best three countries was suggested to be studied first.

Nevertheless, emission intensity of some countries, e.g. the United Kingdom, was found very high. This might be because the reported production was for some chemical plants, not the overall chemical industries, thus yielded a large emission intensity. Therefore, it was also recommended to study their emissions mitigation approaches as they also achieved a dramatic decrease in their total emissions (Figure 3.6)



<u>Figure 3.6</u> Efficiency gain and emission intensity of chemical industries of the United Kingdom

3.4 COMPARISON OF THE CARBON BUDGET OF PETROCHEMICAL INDUSTRIES IN THAILAND AND OTHER THAI INDUSTRIES

The cement and steel industries were selected for the comparison purpose in this study with the reason that both of them were the major and fundamental industries similar to the petrochemical industry. Data of these two industries were obtained from the EIA report of the year 2006 – 2008. However, only data for a few companies were obtained and all of it must be considered as less complete that presented here for the petrochemical industry. Their emission intensities are presented in Table 3.7.

Table 3.7 Comparison of selected Thai industries

Item		Cement	Petrochemical	Steel
Production	(ktonne)	31,650[a]	17,281	8,134[a]
Emission Intensity ($ktonne\ CO_2eq / ktonne_{production}$)		0.3868 – 1.5143	0.6346	0.1320 – 4.0504
Emissions	($ktonne\ CO_2eq$)	12,242-47,929	10,966	1,074-32,945
Export	(Mil. THB)	21,814.32[b]	271,589.88[b]	78,232[c]
	(Mil. GBP)[d]	351.35	4,374.27	1,260.02
	(% of total export)	0.37	4.64	1.34

[a]From National Statistical Office (NSO), Thailand, 2009.

[b]From Bank of Thailand (BOT), Thailand, 2011.

[c]From Office of Industrial Economics (OIE), Thailand 2009.

[d]An average xchange rate of 62.0880 THB per GBP (BOT, 2011).

According to Table 3.7, the petrochemical industries had the good low level of carbon emissions in comparison to other Thai industries. Their emission intensity was about 33% less than an average emission intensity of cement industry and about 70% less than an average emission intensity of steel industry. As a result of different industrial production, the overall emissions of petrochemical industries was about 64% less than cement average emissions and about 36% less than steel average emissions (Figure 3.7).

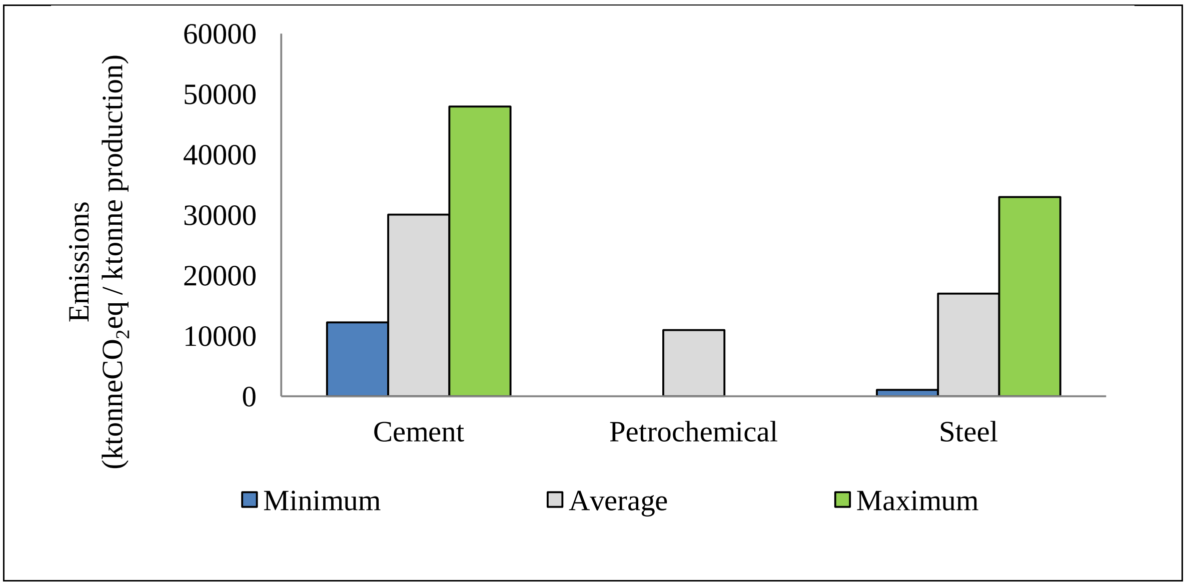


Figure 3.7 Total emissions of selected industries

Considering earning from each industry, petrochemical industries made 271,589.88 million THB or 4,374.27 million GBP from their export in 2008. That amounted to 4.64% of total national export. It was 249,775.56 million THB or 4,022.92 million GBP or 1,145% larger than cement export. And it was 193,357.88 million THB or 3,114.25 million GBP or 247% larger than steel export.

The comparatively low carbon emissions and high incomes indicated that the petrochemical industries were providing a great support to the national economic and properly managing their carbon emissions. However, this did not mean that the other two industries should be called off. Nevertheless, both of them were also very important to the development of the countries. But, they should rather be encouraged to improve their carbon performance in the future.

3.5 CONCLUSION

The total carbon budget of the petrochemical industries in Thailand for the year 2008 was 11 Mtonnes CO_2eq (±10%). Their emission intensity was 0.63 ktonnes CO_2eq per ktonne of production (±10%). Upstream petrochemical industry was the main emission contributor followed by intermediate petrochemical industry and downstream petrochemical industry. The uncertainty analysis suggested that data incompleteness of p-xylene, mixed C4, polystyrene and purified terephthalic acid (PTA) was the main source of error in the developed carbon budget. Acquiring higher quality data of these products would improve accuracy and precision of the total carbon budget.

The statistical data and the developed carbon budget suggested that the petrochemical industries had relatively low carbon emissions in comparison to other Thai industries and chemical industries of other countries. However, it was suggested that the industries should still seek opportunities to enhance their environmental performance for the sustainable development in the future.

CHAPTER 4

CARBON EMISSIONS MITIGATION OPPORTUNITY

CHAPTER 4

CARBON EMISSIONS MITIGATION OPPORTUNITY

4.1 INTRODUCTION

Historical data showed a dramatic growth of the petrochemical industries that correlated with national gross domestic product (GDP) – Figure 4.1. Capacity and production of the petrochemical industries, however, was projected to reach plateau at the year 2010 and 2011 respectively and to remain constant until the year 2015 (PTIT, 2008). The national consumption of petrochemical products would slightly increase during this period.

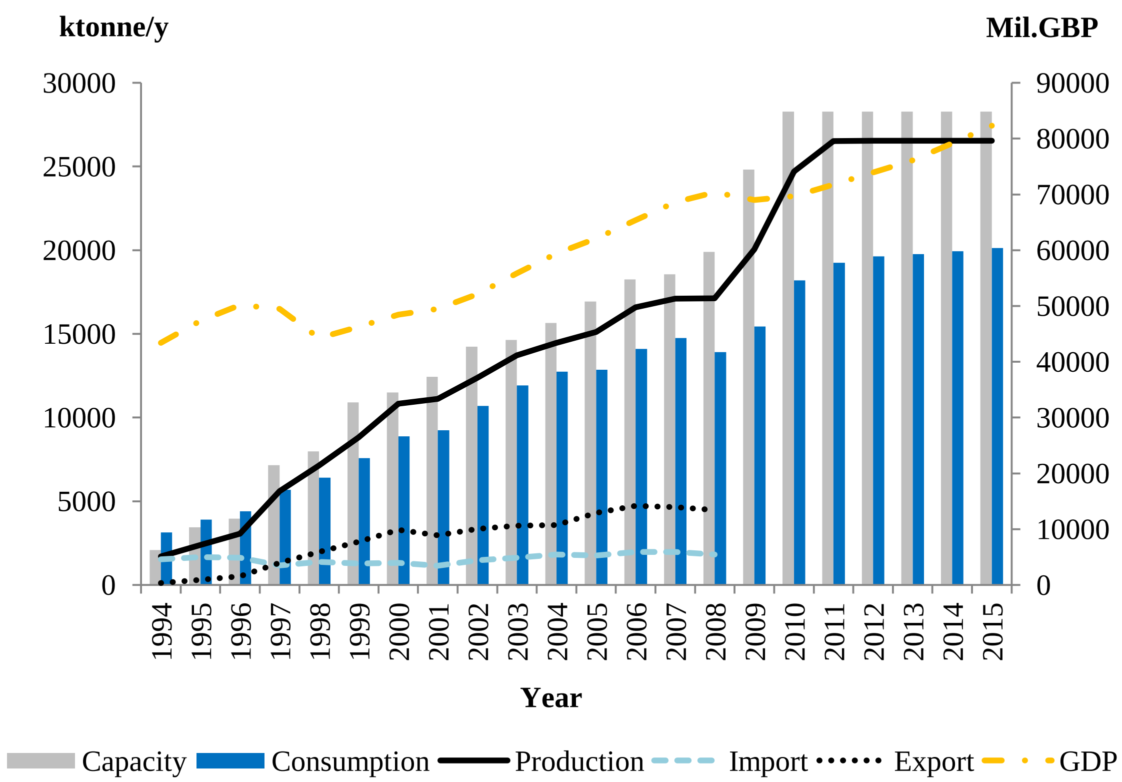


Figure 4.1 Petrochemical activities of the year 1994 to 2015 (PTIT, 2008)

In general, as emissions directly varied with industrial production, emissions of the petrochemical industries were expected to increase from the year 2008 to 2010 and remain at the same level unit the year 2015 if there was no emissions reduction scheme established (Figure 4.2). This emission scenario was called baseline scenario (Box 4.1). On the other hand, either actual emission cut or emission intensity should be observed if proper emissions mitigation action was undertaken.

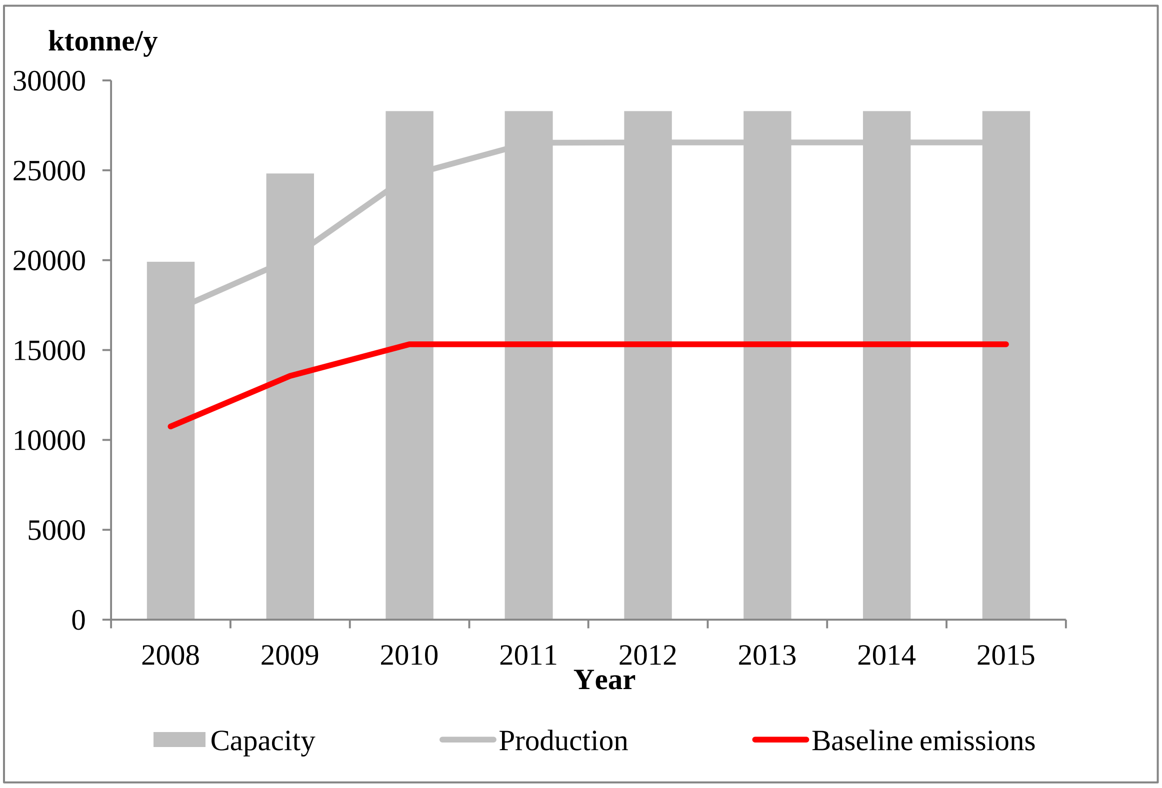


Figure 4.2 Baseline emissions of Thai petrochemical industries.

Box 4.1

Definition of baseline scenario and mitigation scenario

Baseline scenario is a plausible situation in which no specific actions are taken to reduce carbon emissions.

Mitigation scenario is a future emission situation where actions or measures are implemented to reduce emissions

This chapter aims to assess future emissions and possible emissions reduction from and within Thai petrochemical industries.

4.2 CARBON EMISSIONS MITIGATION OPPORTUNITY

4.2.1 Methodology

Generally, there were several manufacturers producing the same petrochemical products. Environmental performance including emissions differed between these manufacturers. The most straightforward and virtually ready-to-apply approach for reducing the emissions was to adopt the current best practice. The concept was to select carbon emission intensity of producers with the best carbon emission performance; then to apply it to estimate emissions of other producers. The new emissions summation would be less than the baseline emissions budget.

There were 4 stages of emissions mitigation estimation.

- Stage 1: Adopt practice of best domestic producer within the same product line
- Stage 2: Adopt practice of best domestic producer but not necessarily in the same product line
- Stage 3: Adopt practice of best international producer
- Stage 4: Select a form of best practice implementation

Common estimation steps of the new carbon emissions in each stage are described as follow:

Step 1: Select the best practice. Basic factors for selecting the best practice were:

1) **Carbon emission intensity or carbon emissions to production ratio**

   Carbon emission intensity of the best practice should be lowest comparing to that of other producers. However, there were many cases that the lowest value was obtained from the producers with the poor level of data completeness. The best practice should be selected from the next lowest value with higher level of data completeness.

2) Level of data completeness

The best practice should be selected from the data with high level of completeness, which was subject to availability. This affected the reliability of the outcome. If the best practice was selected from the data with low level of completeness it would be uncertain whether the low emissions rate was a result of the high effective environmental management or the absence of appropriate data.

In the case that data of the adopter was incomplete and the emission intensity was less than that of the selected best practice, it was suggested to ignore the best practice implementation for that plant and report it as zero gain efficiency, which was defined as a case where efficiency could not be enhanced by using the current practice or technology.

Step 2: Estimate greenhouse emissions of an individual petrochemical plant by multiplying carbon emission intensity of selected best practice by production of each plant as shown in Equation 4.1.

<u>Equation 4.1</u>

Greenhouse gas emissions of an individual petrochemical plant

$$E_{XA} = EI_{BPX} \times P_{XA}$$

Where

E_{XA}	:	Greenhouse gas emissions from petrochemical product X production of petrochemical plant A, tonne CO_2eq
EI_{BPX}	:	Emission intensity of selected best practice of petrochemical product X, tonne CO_2eq/tonne of production
P_{XA}	:	Production of petrochemical product of petrochemical plant A, tonne of production
A	:	Petrochemical plant
X	:	Petrochemical product

Step 3: Calculate total emissions of individual petrochemical product by combining emissions from all producers producing that product as shown in Equation 4.2.

Equation 4.2

Total greenhouse gas emissions from petrochemical production

$$E_X = \sum_A E_{XA}$$

Where

E_X	:	Total amount of greenhouse gas emissions from petrochemical X production, tonne CO_2eq
E_{XA}	:	Greenhouse gas emissions from petrochemical product X production of petrochemical plant A, tonne CO_2eq
A	:	Petrochemical plant
X	:	Petrochemical product

Step 4: Calculate total emissions of the petrochemical industries by combing total emissions of all petrochemical products as shown in Equation 4.3.

Equation 4.3

Total greenhouse gas emissions of petrochemical industries

$$E_T = \sum_X E_x$$

Where

E_T	:	Total amount of greenhouse gas emissions of petrochemical industries, tonne CO_2eq
E_X	:	Total amount of greenhouse gas emissions from petrochemical X production, tonne CO_2eq
X	:	Petrochemical product

Example of calculation is illustrated in Box 4.2.

Box 4.2

Example of estimation of greenhouse gas emissions from petrochemical X production

The petrochemical X was produced from 4 producers with data shown in Table 4.1.

Table 4.1 **Estimation of greenhouse gas (GHG) emissions from petrochemical X production**

Parameter	Producer			
	A	B	C	D
GHG emission intensity (tonnes CO_2eq / tonne$_{production}$)	**0.75**	0.12	0.92	1.56
Level of data completeness	4A	1A	3B	5B
Production (tonnes/ year)	12,000	8,000	15,000	20,000
Baseline GHG emissions (tonnes CO_2eq/y)	0.75x12,000 = 9,000	0.12x8,000 = 960	0.92x15,000 = 13,800	1.56x20,000 = 31,200
New GHG emissions (tonnes CO_2eq/y)	0.75x12,000 = 9,000	0.12x8,000 = 960	0.75x15,000 = 11,250	0.75x20,000 = 15,000

Note. Data shown in this table was modified for reasons of confidentiality.

Bold figure refers selected best practice.

From Table 4.1, producer B had the lowest emission intensity. However, its level of data completeness was poor compared to others. Adoption of emission intensity of producer B would lead to a high level of uncertainty. Producer D had the data at the highest completeness level, but the difference between level 5 and 4 was only the availability of the utility source, while the carbon emission intensity of producer D was about 50% higher than that of producer A. Producer A, with the second best emission intensity and high level of data completeness was selected as the best practice for this product.

After obtaining the best practice, emissions of production of petrochemical X of each plant were estimated by multiplying the carbon emission intensity of the best practice with the production. As plant B was identified as zero gain efficiency case, its emissions were calculated by multiplying its own carbon emission intensity with the production rate.

The new carbon emissions was consequently estimated by adding new emissions of each plant together which were 9,000, 960, 11,250, 15,000 tonnes CO_2eq/tonne$_{production}$. The new emissions budget was 18,750 tonnes CO_2eq or about 34% less than the original emissions.

4.2.2 Mitigation stage 1: adopt practice of best domestic producer within the same product line

At this stage, best practice of each petrochemical product was selected from domestic producers producing the same product. Emissions of the data-incomplete producer and the single producer cases remained unchanged and reported as the zero gain efficiency. The zero gain efficiency cases of each industrial phase are shown in Table 4.2

Table 4.2 Number of studied petrochemical product and zero gain efficiency cases of emissions mitigation stage 1

Industrial phase	Number of Product	Zero Gain Efficiency Case
Upstream petrochemical	8	2
Intermediate petrochemical	12	10
Downstream petrochemical	27	22
Plastics and other derivatives	5	5

The carbon budget of the mitigation stage 1 was 8,235 ktonnes CO_2eq (± 10%), which was 2,713 ktonnes or about 25% less than the baseline budget. The emission intensity was 0.4765 ktonnes CO_2eq per ktonne of production (± 10%). The emissions of the upstream, intermediate and downstream petrochemical industries reduced at the similar magnitude, which was about 24 – 26%, while the plastics and other derivatives industries showed no reduction, of which all cases were reported as zero gain efficiency – Table 4.3.

Table 4.3 Average carbon emission intensity of each industrial phase after applying emissions mitigation stage 1

Industrial Phase	Average Emission Intensity (ktonnes CO_2eq/ktonne$_{production}$)		Difference from Baseline
	Baseline	Mitigation I	
Upstream petrochemical	0.8783 ± 0.0873	0.6504 ± 0.1047	25.95%
Intermediate petrochemical	0.5739 ± 0.0547	0.4357 ± 0.0000	24.08%
Downstream petrochemical	0.4195 ± 0.0014	0.3186 ± 0.0011	24.05%
Plastics and other derivatives	0.3698 ± 0.0000	0.3698 ± 0.0000	0.00%

4.2.3 Mitigation stage 2: adopt practice of best domestic producer but not necessarily in the same product line

Unlike mitigation stage 1, best practice of each petrochemical product in mitigation stage 2 could be selected from domestic producer producing different product. Besides emission intensity and level of data completeness, relevance of the prospective best practice and the adopter should be considered in order to select the best practice. There were 3 selection tiers as follow:

<u>Tier 1</u>: Same industrial phase

<u>Tier 2</u>: Same or similar raw material

<u>Tier 3</u>: Same or similar production process

Data with poor level of completeness and data from lone producer were treated as zero gain efficiency cases and remained unchanged. The zero gain efficiency cases in this stage are reported in Table 4.4

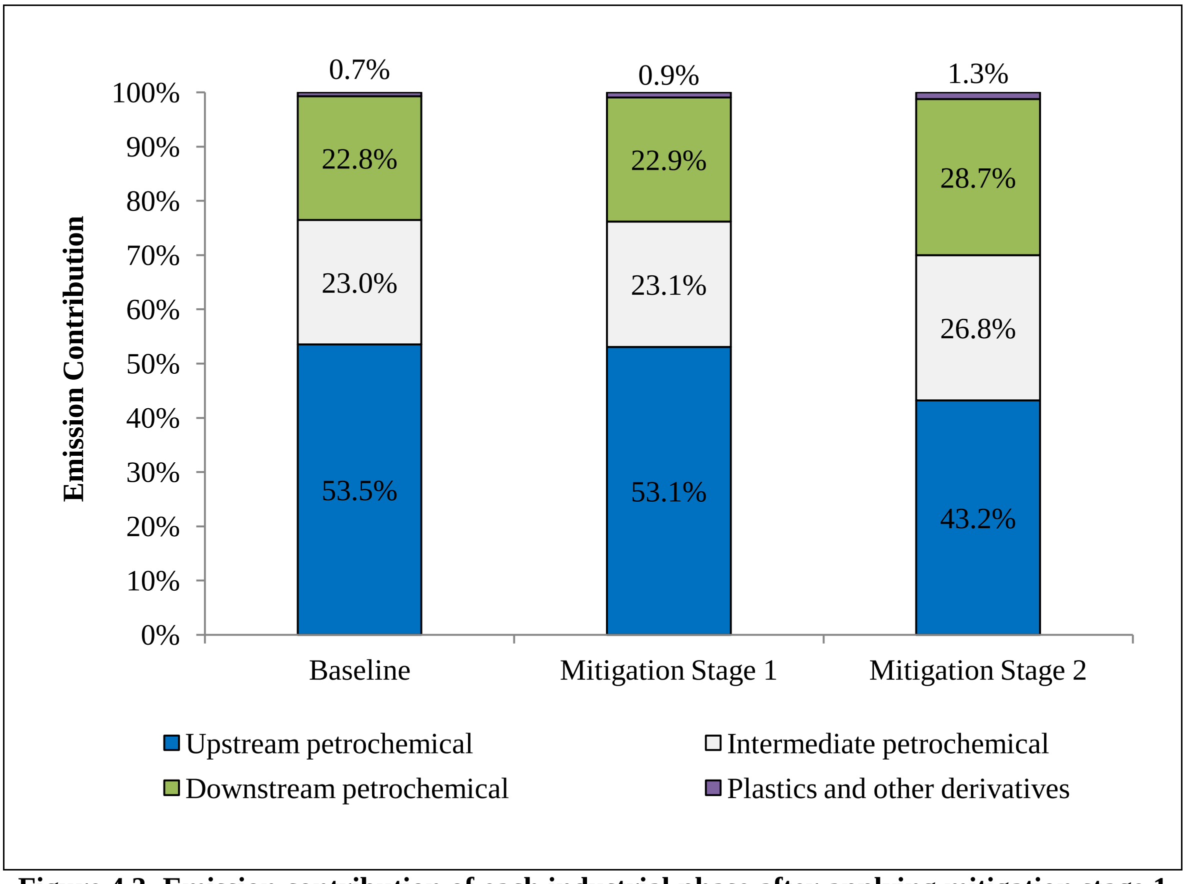
<u>Table 4.4</u> Number of studied petrochemical products and zero gain efficiency cases of the emissions mitigation stage 2

Industrial Phase	Number of Product	Zero Gain Efficiency Case
Upstream petrochemical	8	1
Intermediate petrochemical	12	2
Downstream petrochemical	27	20
Plastics and other derivatives	5	3

The carbon budget of the mitigation stage 2 was 6,105 ktonnes CO_2eq/y (±0.15%), which was 4,861 ktonnes or 44.33% less than the original budget and 2,130 ktonnes or 25.87% less than the stage 1 budget. The emission intensity was 0.3533 ktonnes CO_2eq per ktonne of production (± 0.15%). According to Table 4.5, emission intensity of the upstream petrochemical industries dramatically dropped from the baseline by 54.69%, whereas the intermediate and downstream petrochemical industries had the reduction at about 30-36%. The plastics and other derivatives industries had a small change in the emission intensity.

<u>Table 4.5</u> Average emission intensity of each industrial phase after applying emissions mitigation stage 2

Industrial Phase	Average Emission Intensity ($ktonnes\ CO_2eq/ktonne_{production}$)		Difference from Baseline
	Original budget	Mitigation II	
Upstream petrochemicals	0.8783 ± 0.0873	0.3980 ± 0.0000	54.69%
Intermediate petrochemicals	0.5739 ± 0.0547	0.3685 ± 0.0000	35.79%
Downstream petrochemicals	0.4195 ± 0.0014	0.2922 ± 0.0011	30.35%
Plastics and other derivatives	0.3698 ± 0.0000	0.3696 ± 0.0000	0.05%



<u>Figure 4.3</u> Emission contribution of each industrial phase after applying mitigation stage 1 and 2 comparing to emissions contribution of baseline case

As shown in Figure 4.3, emission contribution of each industrial phase after applying mitigation stage 1 was approximately identical to the baseline case as the reduction percentage of three major contributors were approximately the same. Mitigation stage 2 gave the different result. The emission contribution of the upstream petrochemical industry decreased but was still the major contribution, while the emission contribution of intermediate petrochemical industry and the emission contribution of downstream petrochemical industry changed slightly due to the best practice adoption in mitigation stage 2. The plastics and other derivatives industry contribution remained unchanged as their carbon emission intensity change was very slightly and their contribution portion was very small in comparison to other industrial sectors; thus, their small change did not influence the overall contribution chart.

4.2.4 Mitigation stage 3: adopt practice of best international producer

Emission data of other countries were obtained from national inventories the countries submitted to the United Nations Framework Convention on Climate Change (UNFCCC). These data were reported for the entire chemical industries. In this regard, the best practice was adopted for the calculation of the entire petrochemical industries, not for the individual industrial phase as in stage 1 and 2. Table 4.6 shows the rank of emission intensity of Thai petrochemical industries compared to that of chemical industries of other countries.

Table 4.6 **Emission intensity of chemical industries of the year 2008.**

Country	Emission intensity ($ktonneCO_2eq$ / $ktonne_{Production}$)
Germany	0.2517
United States of America	0.3399
Thailand (mitigation stage 2)[a]	0.3533
Thailand (mitigation stage 1)[a]	0.4765
New Zealand	0.5302
Thailand (baseline)[a]	0.6346
Russian Federation	0.8389
Japan	1.1230
France	1.2383
Austria	1.4401
Canada	2.8161
United Kingdom	3.3304
Belgium	3.3314

[a]Data was for the petrochemical industries only.

The emission intensity of Germany (DE), United States of America (USA) and New Zealand (NZ) were selected as the best practices for estimating potential emissions reduction of Thai petrochemical industries: the result is shown in Table 4.7. The DE practice gave the largest emissions reduction, with 60%, 47% and 29% decrease from baseline, mitigation stage 1 and mitigation stage 2 respectively. The USA emission intensity resulted in the decrease of 46%, 29% and 4% of the original budget, mitigation stage 1 and mitigation stage 2 respectively. The NZ practice decreased the emissions about 16% from the original stage. The result from adopting the NZ practice was compared to the original budget only because mitigation stage 1 and 2 gave smaller emission outcomes.

Table 4.7 Emissions of Thai petrochemical industries after applying international best practices

Parameter	Unit	Source of Best Practice		
		DE	USA	NZ
Total emissions	ktonnes/year	4,349	5,874	9,162
Decrease from baseline	ktonnes/year	6,617	5,092	1,804
	%	60	46	16
Decrease from mitigation stage 1	ktonnes/year	3,886	2,361	
	%	47	29	
Decrease from mitigation stage 2	ktonnes/year	1,756	231	
	%	29	4	

Figure 4.4 shows the baseline emissions of Thai petrochemical industries in comparison to the emissions after applying mitigation stage 1, 2 and 3.

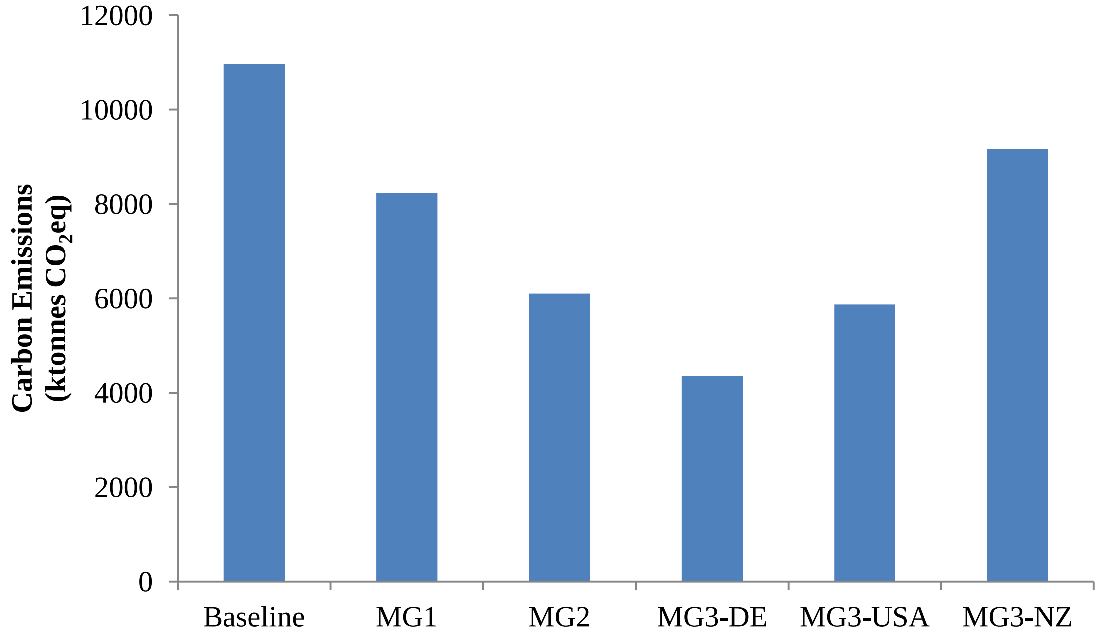


Figure 4.4 **Comparison of baseline emissions (baseline) with emissions from mitigation stage 1 (MG1), mitigation stage 2 (MG2) and mitigation stage 3 (MG3-DE, MG3-USA, MG3-NZ)**

4.2.5 Mitigation stage 4: select a form of best practice implementation

At this stage, future emissions and possible emissions reduction were estimated. The forecast of capacity and production of petrochemical industries was obtained from the Petroleum Institute of Thailand (PTIT). Imminent emissions of the petrochemical industries could be estimated by multiplying emission intensity with the projected production. If there was no emissions mitigation action taken, the emissions of the petrochemical industries would continuously increase from the year 2008 and reach plateau at the year 2011 until the year 2015. However, if proper emissions mitigation actions were taken, future emissions should be improved either in term of emission intensity or actual decrease of emissions flux. The results of mitigation stage 1 – 3 were employed in this mitigation stage in order to assess the feasible reduction, which could be arranged into 4 scenarios.

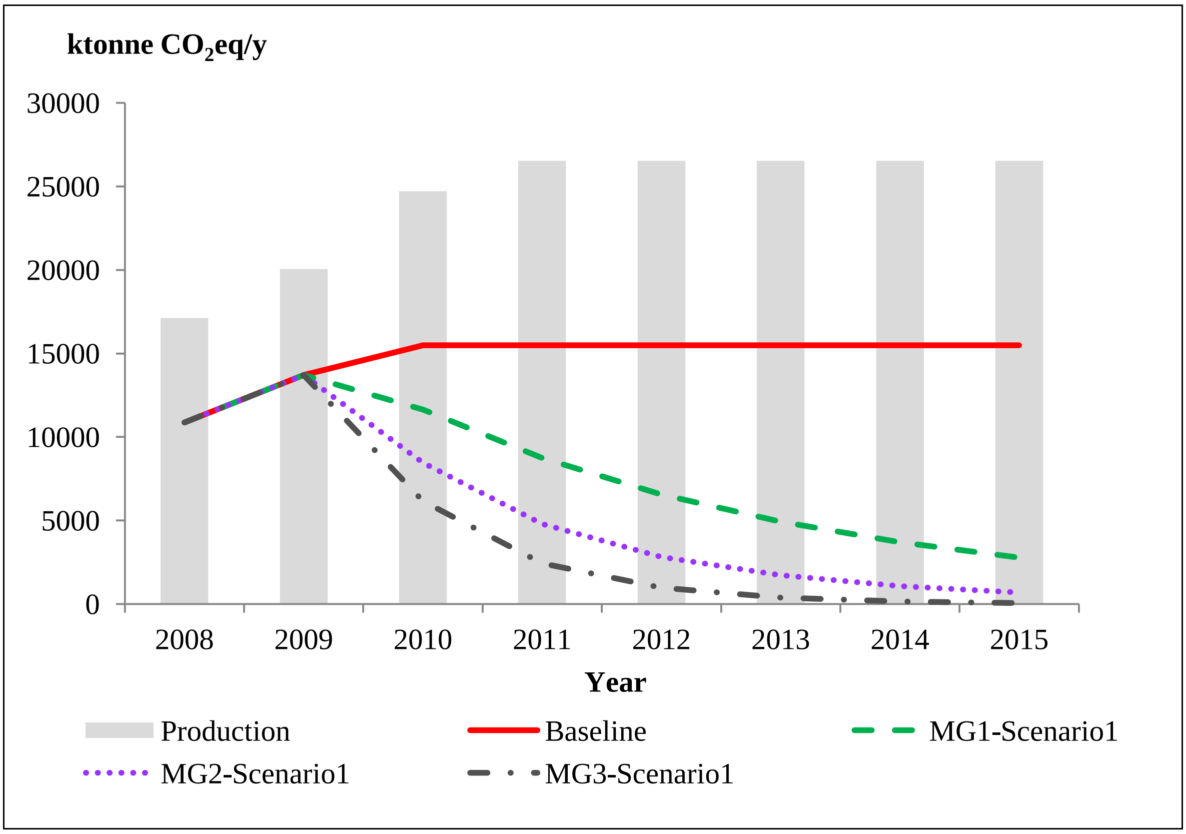
- Scenario 1: adopt the emission intensity of the best practice every year from the year 2010
- Scenario 2: adopt the emission intensity of the best practice in the year 2010, then continue with the 2010 emission intensity
- Scenario 3: adopt the emission intensity of the best practice in the year 2010, then continue with certain emissions reduction ratio
- Scenario 4: adopt the same certain emissions reduction ratio every year from the year 2010

4.2.5.1 Scenario 1: adopt the emission intensity of the best practice every year from the year 2010

This scenario employed emission intensity of the best practice from stage 1 – 3 to estimate the emissions of the industries from the year 2010 to 2015. The emission intensity of Germany was selected as the representative of stage 3 because it was the lowest value compared to that of other countries. Table 4.8 and Figure 4.5 show result of the emissions mitigation scenario 1.

Table 4.8 Carbon emissions of petrochemical industries under emissions mitigation scenario 1 (unit: ktonne CO_2eq/y)

Case	Year							
	2008	2009	2010	2011	2012	2013	2014	2015
Baseline	10,966	13,835	15,642	15,642	15,642	15,642	15,642	15,643
Mitigation stage 1	10,966	13,835	11,813	8,922	6,738	5,090	3,844	2,904
Mitigation stage 2	10,966	13,835	8,447	4,761	2,796	1,703	1,069	687
Mitigation stage 3	10,966	13,835	6,161	2,427	956	376	148	58



<u>Figure 4.5</u> Carbon emissions mitigation of the petrochemical industries in Thailand – scenario 1

The emissions of the petrochemical industries were estimated to increase in the year 2009 as there was no emissions reduction applied. However, after applying the emissions reduction rates of the best practice from each mitigation stage, the emissions were predicted to decrease in the year 2010 to 2011 despite an expected increase in industrial production. This might be because the applied carbon emission intensity had higher influence on the overall emissions than the production did. The emissions continued dramatically decreased in the year 2012 to 2015 as the same reduction rate was still applied while the industrial production remained constant.

4.2.5.2 Scenario 2: adopt the emission intensity of the best practice in the year 2010, then continue with the 2010 emission intensity

Similar to the first scenario, carbon emissions reduction rates from mitigation stage 1 – 3 were employed to estimate the emissions of the industries in the year 2010. Then, emission intensity of the year 2010 was continually used to estimate the emissions of the year 2011 to 2015. Table 4.9 and Figure 4.6 show result of the emissions mitigation scenario 2.

Table 4.9 **Carbon emissions of petrochemical industries under emissions mitigation scenario 2 (unit: ktonne CO_2eq/y)**

Case	Year							
	2008	2009	2010	2011	2012	2013	2014	2015
Baseline	10,966	13,835	15,642	15,642	15,642	15,642	15,642	15,643
Mitigation stage 1	10,966	13,835	11,813	11,813	11,813	11,813	11,813	11,813
Mitigation stage 2	10,966	13,835	8,447	8,447	8,447	8,447	8,447	8,447
Mitigation stage 3	10,966	13,835	6,161	6,161	6,161	6,161	6,161	6,161

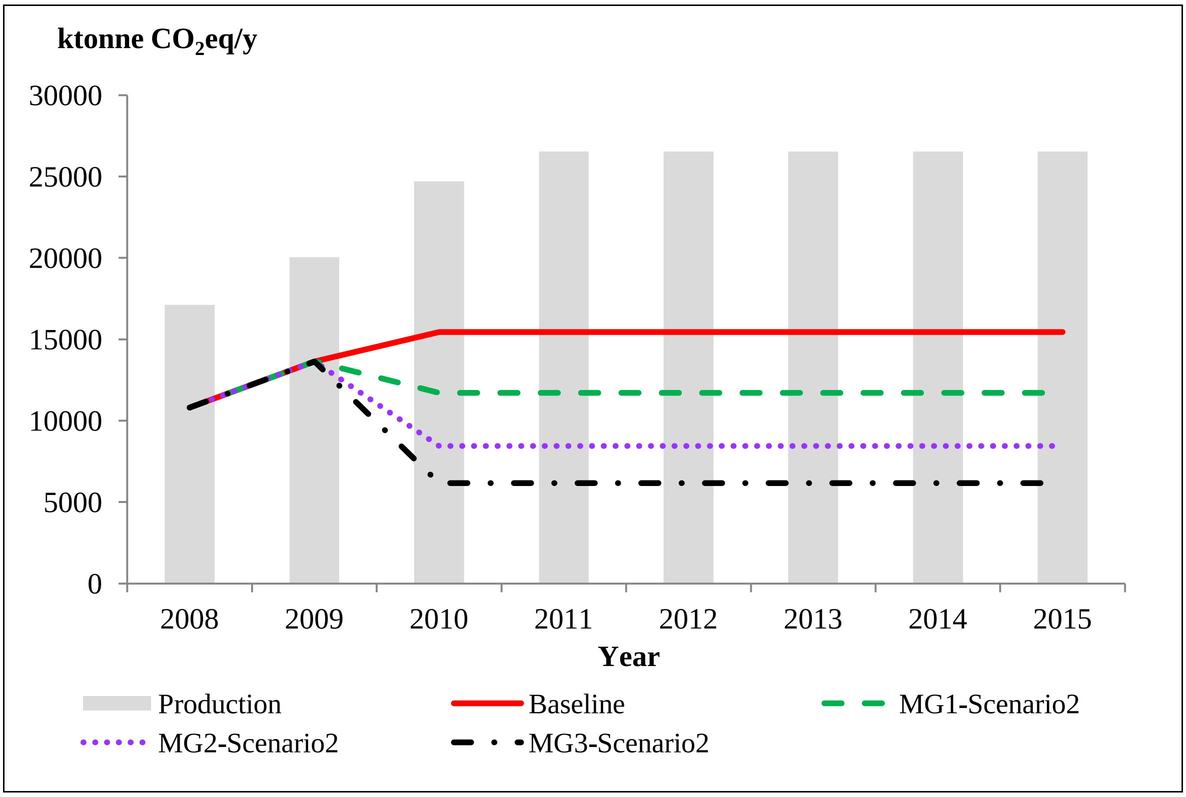


Figure 4.6 **Carbon emissions mitigation of the petrochemical industries in Thailand – scenario 2**

It was found that emissions of the petrochemical industries during the year 2008 – 2010 were similar to those of scenario 1. Emissions in the year 2009 increased because there was no emissions mitigation undertaken. Emissions in the year 2010 declined as the emissions reduction rates from mitigation stage 1 – 3 were applied, even with increased production. Emissions from the year 2011 to 2015 were estimated by multiplying emission intensity of the year 2010 with the projected production, therefore the emissions remained constant as the production of this period was steady.

4.2.5.3 Scenario 3: adopt the emission intensity of the best practice in the year 2010, then continue with certain emissions reduction ratio

The emission intensity of the best practice from stage 1 – 3 was employed to estimate emissions of the petrochemical industries in the year 2010. Then, a certain reduction rate was applied in the later years.

The historical data of countries, namely France (FR), Germany (DE), Japan (JP), New Zealand (NZ), United Kingdom (UK) and United States of America (USA) were examined to assist in identifying the proper reduction rate to be applied after year 2010. The emissions data of these countries were obtained from their national inventories submitted to UNFCCC.

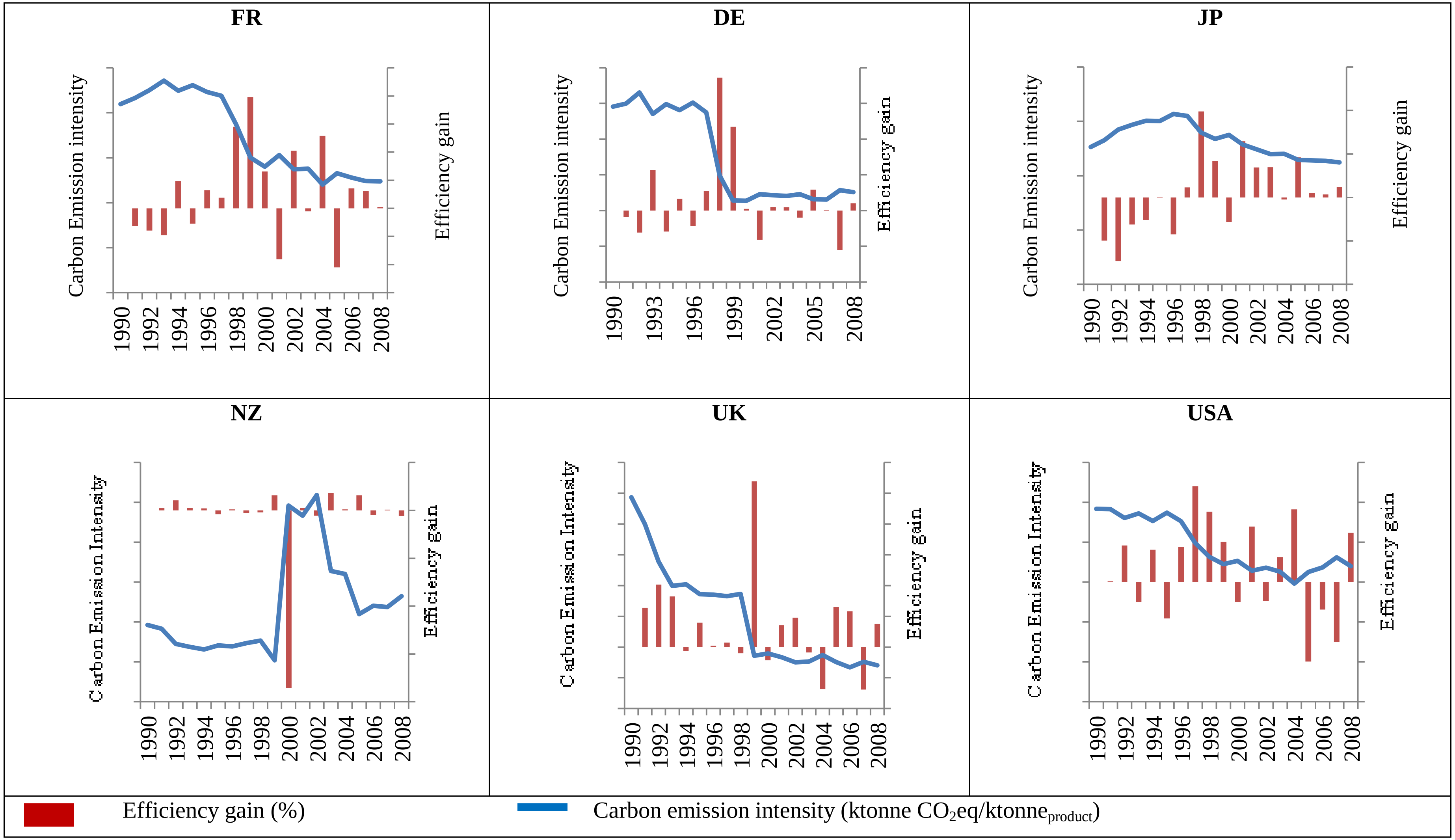


Figure 4.7 **Efficiency gain and carbon emission intensity of various countries**

<u>Table 4.10</u> Efficiency gain in chemical industries of selected countries

Year	Efficiency Gain					
	FR	DE	JP	NZ	UK	USA
1990	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1991	-3.2%	-1.8%	-5.0%	4.8%	12.7%	0.1%
1992	-4.0%	-6.1%	-7.3%	20.9%	20.3%	4.6%
1993	-4.8%	11.4%	-3.1%	5.3%	16.4%	-2.5%
1994	4.9%	-5.9%	-2.6%	4.4%	-1.2%	4.1%
1995	-2.8%	3.3%	0.1%	-7.8%	7.9%	-4.5%
1996	3.2%	-4.4%	-4.3%	2.0%	0.4%	4.4%
1997	1.9%	5.4%	1.2%	-5.8%	1.4%	12.0%
1998	14.5%	37.2%	9.9%	-4.3%	-2.0%	8.8%
1999	19.8%	23.4%	4.2%	31.9%	53.9%	5.0%
2000	6.6%	0.5%	-2.8%	-371.5%	-4.3%	-2.5%
2001	-9.1%	-8.2%	6.5%	5.1%	7.1%	7.0%
2002	10.3%	1.0%	3.4%	-11.1%	9.6%	-2.3%
2003	-0.5%	0.9%	3.5%	36.8%	-1.8%	3.1%
2004	12.9%	-2.0%	-0.2%	2.3%	-13.7%	9.1%
2005	-10.5%	5.8%	4.6%	31.4%	13.0%	-10.0%
2006	3.5%	0.2%	0.5%	-9.7%	11.6%	-3.4%
2007	3.1%	-11.1%	0.3%	1.4%	-13.8%	-7.5%
2008	0.2%	2.0%	1.2%	-11.5%	7.5%	6.2%
Max	19.8%	37.2%	9.9%	36.8%	53.9%	12.0%
Min (positive value)	0.2%	0.2%	0.1%	1.4%	0.4%	0.1%
Average	2.7%	1.7%	0.5%	5.3%	6.6%	2.4%

From Figure 4.7, the downward trends of the carbon emission intensity were observed in most cases. The data of the emissions from energy sector of New Zealand of the year 1990 – 1999 was absent. The same kind of data was available from the year 2000. Thus, as the total emissions were the summation of the emissions from the energy sector and emissions from the industrial processes, the unusual tremendous increase in the carbon emission intensity was observed in the year 2000 for New Zealand.

There was a large fluctuation of the efficiency gain over time in all cases as shown in Table 4.10. The minimum gain was 0.1% in Germany and Japan and the maximum gain was 53.9% in the United Kingdom. The average efficiency gain per year across all the countries considered ranged between 0.5 – 6.6%. Based on the conservative approach, the minimum efficiency gain of 0.1% was employed in this mitigation scenario.

Table 4.11 and Figure 4.8 show result of the emissions mitigation scenario 3.

Table 4.11 Carbon emissions of petrochemical industries under emissions mitigation scenario 3 (unit: ktonne CO_2eq/y)

Case	Year							
	2008	2009	2010	2011	2012	2013	2014	2015
Baseline	10,966	13,835	15,642	15,642	15,642	15,642	15,642	15,643
Mitigation stage 1	10,966	13,835	11,813	11,801	11,789	11,778	11,766	11,754
Mitigation stage 2	10,966	13,835	8,447	8,439	8,430	8,422	8,413	8,405
Mitigation stage 3	10,966	13,835	6,161	6,155	6,149	6,143	6,136	6,130

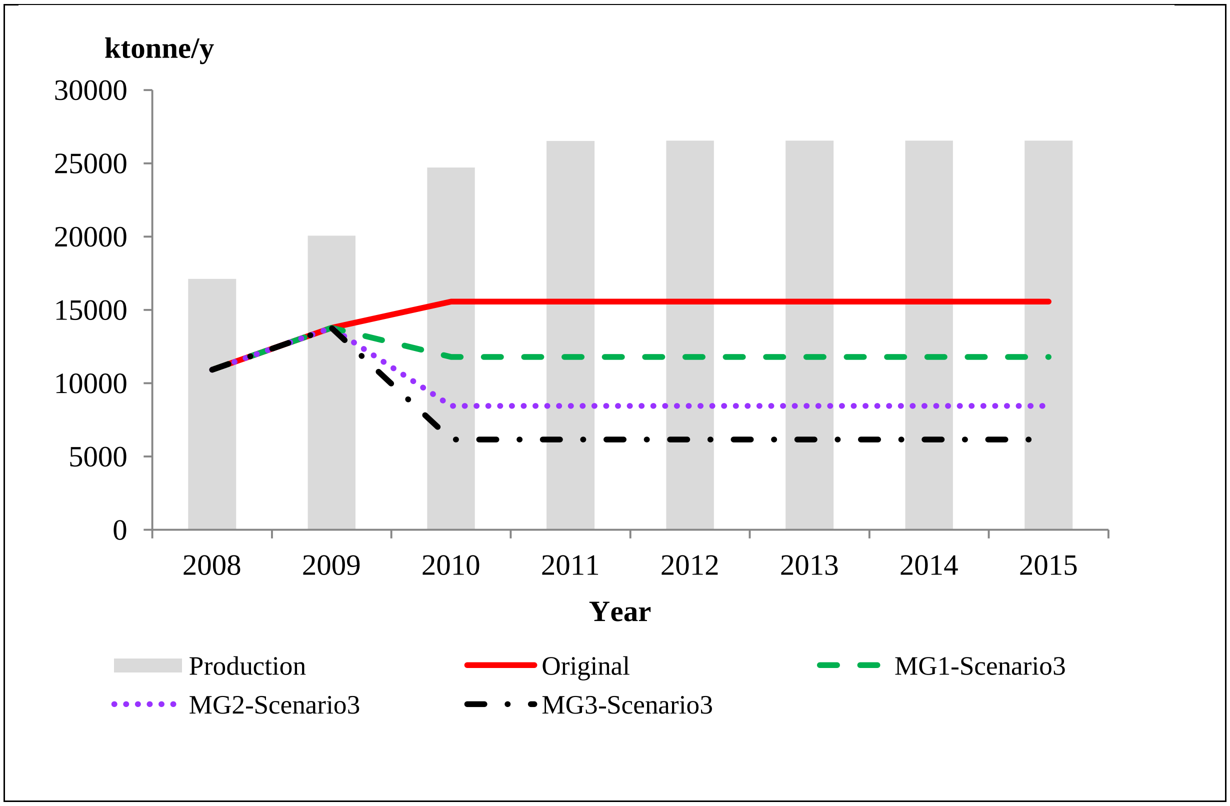


Figure 4.8 **Carbon emissions mitigation of the petrochemical industries in Thailand - scenario 3**

Regarding Figure 4.8, the emissions of the petrochemical industries in the year 2009 – 2010 were projected in the same manner as in scenario 1 and 2. The emissions increased in the year 2009 and decreased in the year 2010. After that, as the emissions reduction of 0.1% was applied from the year 2011, the overall emissions decreased slightly until the year 2015.

4.2.5.4 Scenario 4: adopt the same certain emissions reduction ratio every year from the year 2010

This scenario employed the efficiency gain of the international best producer, Germany, as the emissions reduction rate. The minimum efficiency gain of 0.1% was adopted in case 1 and the average efficiency gain of 1.7% was adopted in case 2. The result was shown in Table 4.12 and Figure 4.9.

Table 4.12 **Carbon emissions of petrochemical industries under emissions mitigation scenario 4 (unit: ktonne CO_2eq/y)**

Case	**Year**							
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Baseline	10,966	13,835	15,642	15,642	15,642	15,642	15,642	15,643
Case 1	10,966	13,835	15,627	15,613	15,598	15,584	15,569	15,555
Case 2	10,966	13,835	15,380	15,123	14,870	14,621	14,377	14,136

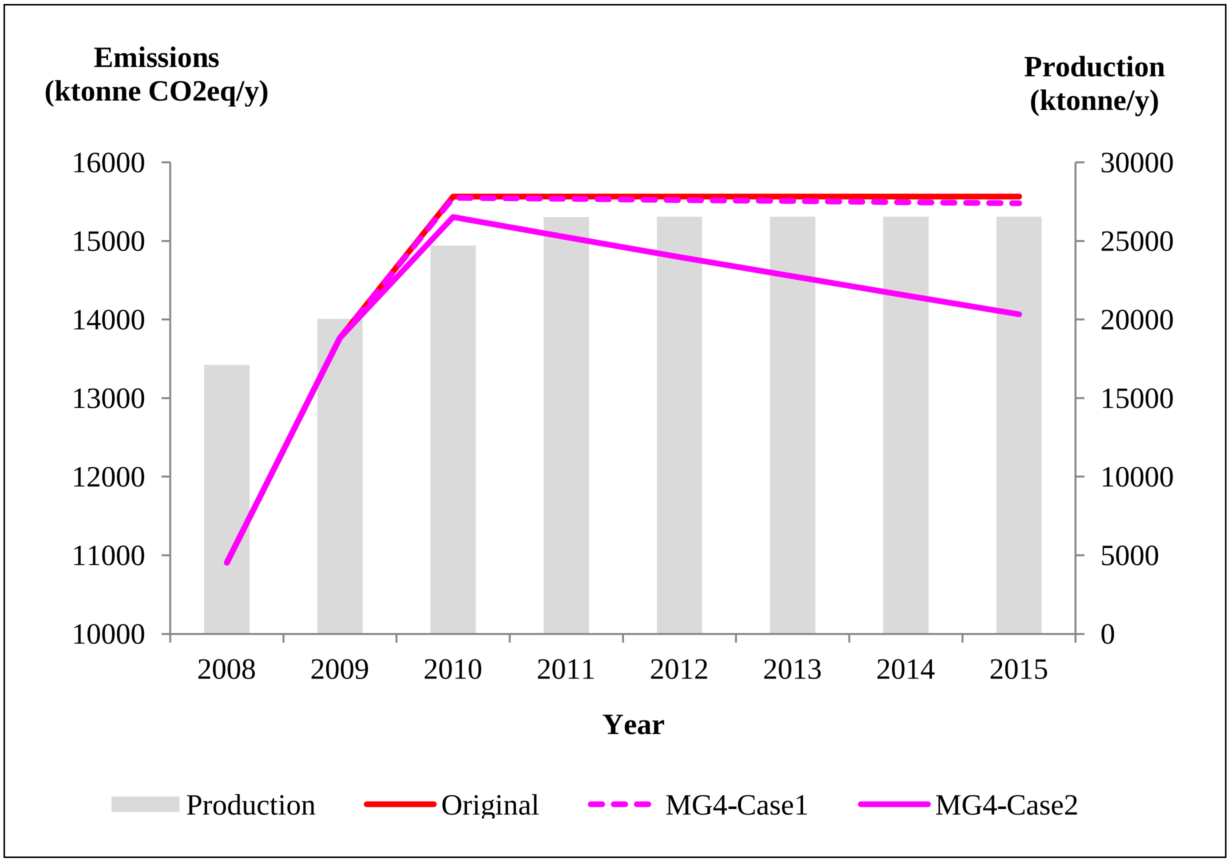


Figure 4.9 **Carbon emissions mitigation of the petrochemical industries in Thailand - scenario 4**

The emissions of both cases increased from the year 2008 to 2010. After that the emissions decreased gradually. The actual cut of emissions flux could be observed in this scenario because the industrial production was constant while emissions reduction efficiency was obtained. However, the decrease in case 1 was barely noticeable due to the applied emissions mitigation factor was very small.

4.2.5.5 Selection of a form of best practice implementation

Comparing results from 4 scenarios, the first scenario gave the least feasible outcome. The result showed the dramatic decrease of emissions over time despite the high production rate and the emissions was likely to reach zero in the future, which was certainly unachievable. Scenario 2 and 3 gave similar results, which were both feasible. By applying the current best practice, the emission intensity of emissions could be greatly reduced or, in the other words, the emissions reduction efficiency was obtained. After that the emission intensity could be maintained (scenario 2) or the extra emissions reduction efficiency could be further achieved (scenario 3). Scenario 4 also gave the possible outcome, however the small amount of efficiency gain might not be satisfactory.

As the petrochemical industries in Thailand were driving towards the environmental sustainability, the third scenario would give the most potential outcome. Not only was the large emission intensity reduction obtained at the first period of best practice implementation, but the annual efficiency would be achieved in the later years, thus would assist the industries in the environmental management development.

Table 4.13 **Total emissions reduction of scenario 3 at the year 2015 comparing to baseline emissions**

Case	Total Reduction from Baseline Emissions
Mitigation stage 1	25%
Mitigation stage 2	46%
Mitigation stage 3	61%

This third scenario yield about 25-61% of emissions reduction from the baseline case (Table 4.13). Considering the maximum efficiency gain in chemical industries of other countries, which was in a range of about 10–54% (Table 4.10), the projected range of 25–61% of the emissions reduction of Thai petrochemical industries was likely to be achievable.

4.3 CONCLUSION

In general, emissions directly changed with the change of production. If production increased, emissions also increased. In case of increasing production, an actual cut of emissions flux might not be obviously seen even though there was a proper emissions mitigation action taken. Other efficiency-related factors such as emission intensity should be assessed as an alternative. However, if the production was constant while the proper mitigation action was implemented, a decrease of emissions level could be observed.

The prospective emissions of Thai petrochemical industries were estimated to be 15,643 ktonne CO_2eq in the year 2015. However, it was found that the emissions could be reduced between 25-61% through effectively adopting current best practice and efficiency. This suggested that Thai petrochemical industries did not need to resort to difficult or extraordinary solutions to make a substantial emissions reduction: there is a need for good investment in existing effective technologies, engineering and environmental management. Nevertheless, it is not always simple to obtain best practice technology, engineering or management as it involves know-how confidentially and competitiveness concern. Joint ventures with companies possessing such capacities may be required.

CHAPTER 5

CARBON EMISSIONS MITIGATION

CHAPTER 5

CARBON EMISSIONS MITIGATION STRATEGIES

5.1 INTRODUCTION

5.1.1 Current carbon emissions status and the need of the carbon emissions reduction

Thailand, along with over 150 other nations, signed the United Nations Framework Convention on Climate Change (UNFCCC) at the United Nations Conference on Environment and Development (UNCED) in Rio De Janeiro, in June 1992 and ratified the Convention in March 1995 as Non Annex I country (Ministry of Science, Technology and Environment (MSTE) of Thailand, 2000). This meant that there was no carbon abatement obligation for Thailand under the Kyoto protocol. However, Thailand had voluntarily reduced its GHG emissions through the implementation of clean development mechanism (CDM).

Chapter 3 demonstrated that total carbon budget of the petrochemical industries in Thailand was relatively low in comparison to respective chemical industries of other countries and comparatively low with respect to other Thai industries. Further, that total carbon budget of the petrochemical industries of Thailand was low relative to these comparator groups both in terms of emission intensity and absolute emissions amount, the Thai petrochemical industry does not presently have mandatory carbon emissions abatement targets that it has to conform with. Nevertheless, these petrochemical industries should advance their environmental performance through low-carbon technology development, which involves: improvement of emissions reduction; implementation of less- or zero carbon intensive alternatives; energy efficiency enhancement and cleaner production processes. These approaches would lead to lower environmental management expenditure, a greater green competitiveness, and a sustainable development of the industries; and eventually a better living standard for the country.

5.1.2 Stakeholders

In order to achieve any carbon emissions reductions, it was essential to obtain robust cooperation from all relevant stakeholders: the petrochemical industries themselves; the government to provide policy and regulatory support; the financial institutions to provide the financial support; the academia and environmental third parties to provide advice and research; and other industries and emissions sources to make their own contribution to carbon emissions reduction.

5.1.3 Project feasibility consideration

Developing the new low-carbon technologies needs to assess the feasibility of the project in the following ways.

5.1.3.1 Technical feasibility

Technical feasibility is to assess whether the required resources are available and the developed technology is technically practical.

5.1.3.2 Economic feasibility

It might be possible that the project is technically feasible but it requires huge investment and the rate of return is low. The economic feasibility analyses the costs and the benefits the project would deliver in both the short- and the long-term.

5.1.3.3 Operational feasibility

Operational feasibility assesses whether the technology could be implemented if it was developed. The involvement of the users in the project designs would reduce the probability of resistance towards any new technologies.

5.1.3.4 Legal feasibility

The project should ensure that it does not violate any of the current laws and regulations, or indeed any foreseeable changes in legislation.

5.1.4 Carbon emissions reduction indicator

Generally, carbon emissions are the function of carbon content in fuel and feedstock, and process efficiency. As a result, carbon efficiency is not straightforward to measure and monitor. The indicator for emissions reduction observation is therefore assumed to be equivalent to the energy intensity (Department for Environment Food and Rural Affairs (DEFRA) of the United Kingdom, 2004).

Energy intensity is a measure of energy efficiency of the production. It is calculated as units of energy (e.g. terajoule) per unit of production (e.g. tonne). High energy intensity indicates high energy required in order to produce a unit of the product, which in turn is assumed to reflect a high level of carbon emissions; conversely low energy intensity indicates lower energy required for the production which would be expected in turn to result in smaller amounts of carbon emissions. However, it is always important to identify the type of energy consumed as different type of energy generates different amounts of carbon emission.

5.1.5 Drivers and incentives

Important drivers for advancing carbon emissions reduction and develop low-carbon technologies are as follow:

5.1.5.1 Future carbon obligations

Although there is no carbon emissions obligation at present upon Thai industry, it is expected that, with the increasing concern about the climate change problem, carbon emissions regulations would come into force in the near future. In addition, other carbon policies such as carbon pricing would stimulate the emissions reduction enhancement.

5.1.5.2 Conventional finite feedstock

Fossil fuel resources, which are primary feedstocks of the petrochemical industries, are finite, and shortage of supply is likely to happen. Therefore, without renewable or alternative sources, the fossil-based products would eventually become overpriced (Office of Energy Efficiency and Renewable Energy (EERE) of USA, 1999). Thus, higher fossil fuel prices encourage investing in a lower carbon economy.

5.1.5.3 Financial incentive

Low-carbon technology could result in the saving in energy cost. Additionally, the official incentives, for example, tax reduction for the use of renewable or recycling materials could decrease the emissions from waste sector as well as increase the development of renewables.

5.1.5.4 Good image

Being recognised as an environmentally responsible producer can result in an improved public image for the enterprise, thus increases its green competitiveness in today's highly competitive market.

5.1.5.5 Others

Besides all the direct benefits, the investment in the low-carbon technology development has the co-benefit to the nation in term of job creation.

5.1.6 Barriers

There are 3 key challenges in stimulating low-carbon technologies including emissions abatement advances and zero emission productions: technological, financial and institutional barriers.

5.1.6.1 Technological barriers

5.1.6.1.A) Lack of emerging efficient technologies

In order to reduce the large amount of emissions, present technologies might not be sufficient. This requires more research and development on new technologies in both emissions mitigation and energy efficiency. However, investment in such technologies might be risky. Thus, mechanisms to strengthen the investment incentives such as carbon pricing and low-carbon obligations are needed (Committee on Climate Change (CCC) of the United Kingdom, 2009). In addition, there should be supportive mechanism to assure that there would be the back-up market for the newly developed technologies.

5.1.6.1.B) Lack of expertise and example of successful case

The low-carbon technology is still in its infancy, especially in Thailand. Besides, the successful cases from project designs to business diffusion have not been widely demonstrated (GOT, 2009). Capacity building is a priority to lessen this barrier.

5.1.6.1.C) General technical hassle

An example of this barrier is the hassle of finding installers (DEFRA, 2004). There should be a national focal point to provide general services such as: legal consultation; an alternatives and renewables supplier database; and energy advice over the low carbon transition.

5.1.6.2 <u>Economic barriers</u>

5.1.6.2.A) High upfront cost

High upfront cost of new investments could cause entrepreneurs to hesitate before investing in low-carbon technologies, especially for those with limited resources and which may not deem energy costs as a priority when considering cost competitiveness (Executive Agency for Competitiveness and Innovation of the European Commission (EACI), 2009). Financial supports from the government and financial institutes are required. More importantly, the perception of low-carbon technologies as the extra cost should be changed. They should be viewed as worthy investment, which would, in turn, increase the competitiveness.

5.1.6.2.B) Hesitation of financial institutes

Financial institutes might be uncertain about the likelihood of success of the projects, consequently they could be reluctant to provide financial support e.g. loans for investment (GOT, 2009). Examples of economically successful cases would raise a confidence of the financial institutes over the future of low-carbon technology ventures.

5.1.6.3 <u>Institutional barriers</u>

5.1.6.3.A) Lack of interest

Entrepreneurs might not be interested in investing in low-carbon technologies or further emissions reduction as they do not see potential benefits or necessaries. Raising awareness, particularly among senior staff, of the importance of emissions abatement and a strong lead from the government would influence actions towards low-carbon technology development.

5.1.6.3.B) Uncertain returns

Investment in low-carbon technology might not suddenly lead to additional revenue, and thus not attract entrepreneurs. However, the investment in low-carbon technologies, for example, energy efficiency enhancement could lead to substantial savings in electricity bills (GOT, 2009).

5.1.7 Other issues

5.1.7.1 <u>Carbon leakage</u>

Carbon leakage was defined as an increase in emissions outside the regulated area as a direct result of the policy to cap emissions in that area (Box 1.3). The policy maker must ensure that regulation to solve one issue would not lead to other issues such as carbon leakage.

5.1.7.2 <u>Double counting</u>

With the intention to foster emissions abatement, there might be many incentives, particularly the financial one, available for emissions reduction projects to take benefits from. Thus, there should be mechanisms that control the duplication of receiving incentives. For example, a carbon emissions reduction project must be financed from either an energy efficiency fund or a greenhouse gas emissions reduction fund, even though the project is eligible for both funds.

This chapter discusses the promising areas for carbon emissions mitigation in the petrochemical industries, the fundamental support from the government and the contribution in emissions abatement of other sectors. However, this research does not attempt to map the firm policies but seeks to set out the broad direction of the emissions mitigation approaches.

5.2 AREAS FOR CARBON EMISSIONS MITIGATION IN THE INDUSTRIAL SECTOR

Emissions reduction could generally be achieved in 2 manners. The first one was the reduction of emissions generation or emission intensity. The concept was to apply technologies or measures that helped decrease the generation of emissions, thus it could actually cut down the emissions or reduce the emission intensity in the case that production was increasing. However, the scope of emissions reduction in the petrochemical industries was limited as carbon emissions were mainly from combustion process, which were not easy to replace. Another area was the reduction of emission release. This area did not cut down the emissions generation but helped decrease the release of the emissions. Thus, emissions were still being generated but it allowed more time to manage the emissions properly. It was expected that a combination of 2 areas would give a better solution.

5.2.1 Reduction of emissions generation or emission intensity

5.2.1.1 Low carbon material and energy

The petrochemical industries consumed fossil-based products as their main raw materials and energy. Carbon emissions were therefore inevitably generated along with petrochemical products. Besides the emissions concern, hydrocarbon sources were finite and often imported. Regardless of the debate in timing of petroleum supply declining, the demand increased as the population expanded and standard of living generally increased. Thus, the alternative low-carbon supply should provide the environmentally sound solution and would help meet the increasing demand. However, it was not expected that the alternative resources would entirely substitute the hydrocarbon sources within this near future nor were competing directly with them (EERE, 1999). On the other hand, they should be considered as a necessary supplement and, as a result, should be developed.

Besides reduction of carbon emissions, the development of alternative sources had co-benefits in terms of the reduction of imported petroleum products; the diversification of the industrial production away from the nonrenewables; and the generation of local income and job creation (GOT, 2009). In addition, an effective coordinated effort of all sectors including the government, industry, agriculture sector and other supportive sectors, e.g. academia and environmental third parties, was needed for the success of the renewable resource development.

5.2.1.1.A) Feedstock material:

Plant-derived materials were ones of the promising alternative sources for the petrochemical production (EERE, 1999). However, the knowledge of the plant-derived material development was still at an early stage unlike the fossil-based feedstocks where acquisition techniques and standards have been thoroughly developed and entrenched. The success of the alternative supply required more research and development, for example plant genetic engineering for the production of feedstocks with carbon molecules appropriate for the production of petrochemicals. High performance multifunctional catalyst was another research area that should be focused.

Additionally, supply consistency in terms of quantity and quality must be well managed to ensure the production viability. Other relevant factors such as price per volume and geographical location should be also clearly defined on an annual production basis (EERE, 1999).

5.2.1.1.B) Energy:

According to Figure 3.2 of Chapter 3, the plastics and other derivatives industry had only 1% emissions contribution while the upstream, intermediate and downstream phase constituted 53%, 23% and 23% of total emissions respectively. Thus, it was more appropriate to focus on the major emissions contributors: upstream, intermediate and downstream petrochemical industries.

From the study, it was found that there were three forms of energy consumed in the petrochemical industries: electricity, steam and fuel. The overall consumption of each energy type is shown in Figure 5.1. From the chart, fuel was the major energy consumed by the petrochemical industries with 55% consumption, followed by steam with 38% consumption and electricity with 7% of consumption. Fuel and steam were most consumed by the upstream petrochemical phase while electricity was the most important energy for the downstream petrochemical industries (Figure 5.2)

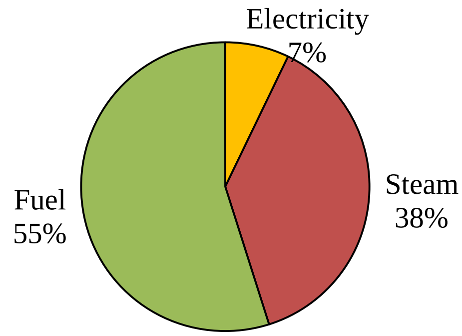
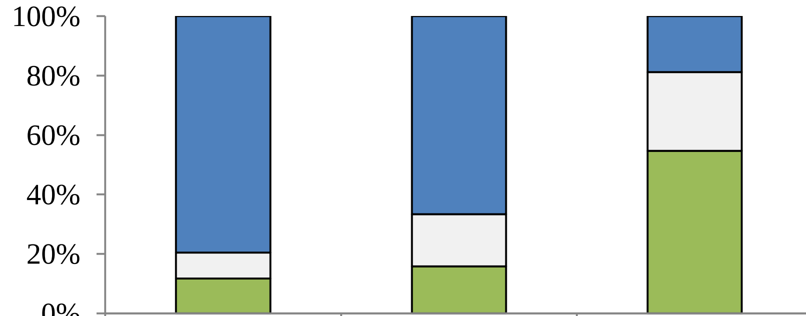


Figure 5.1 **Energy consumption of the overall petrochemical industries in Thailand**



	Fuel	Steam	Electricity
Upstream petrochemical	79.53%	66.62%	18.76%
Intermediate petrochemical	8.72%	17.57%	26.56%
Downstream petrochemical	11.74%	15.81%	54.68%

Figure 5.2 **Percentage of energy consumption in each industrial phase**

Almost 80% of consumed fuel was used in the upstream petrochemical industries (Figure 5.2). As, besides the consumption in the production process, many of the upstream petrochemical plants had their own onsite utility generation units, they required a large amount of fuel. Main fuels consumed were fuel gas and natural gas, which together accounted for almost 90% of the total fuel consumption (Figure 5.3). Fuel gas was methane (CH_4) rich byproduct from the production process and gave low carbon emissions after combustion comparing to higher carbon content fuel. Natural gas was known as clean, low-carbon fuel with emission factor of 56.10 g CO_2eq/MJ (Table 2.5, Chapter 2), which was almost 25% lower than emission factor of fuel oil (73.16 – 74.05 g/MJ). It could be concluded that the petrochemical industries already utilised clean fuel. Minor fuels, namely LPG, fuel oil and diesel, might be substituted by cleaner fuels for better emissions performance in the future, but it was not considered as the first priority.

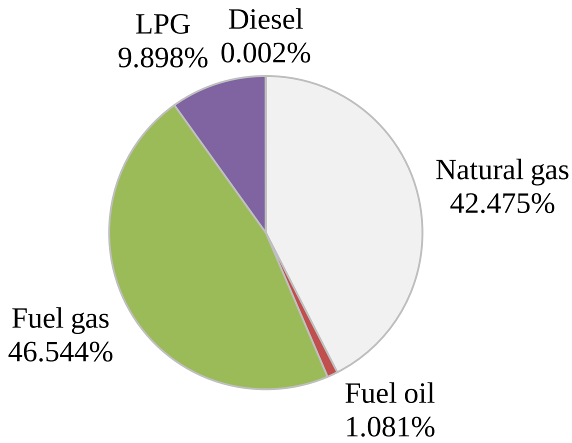


Figure 5.3 Fuel consumption of the overall petrochemical industries in Thailand

Although many petrochemical plants, particularly the upstream phase, produced their own steam and electricity at their own power generation units, a number of factories imported power from outside source. The largest power supplier in Thailand was the Electricity Generating Authority of Thailand (EGAT), which alone contributed 43% to the national production capacity (Table 5.1). Other power sources of the country were independent power producers (IPP), small power producers (SPP), and external suppliers. It was assumed in this study that, unless otherwise identified, the petrochemical industries imported their power from EGAT.

Table 5.1 Thailand's power generator

Source	Production Share
Electricity Generating Authority of Thailand	43.0%
Independent power producers	45.7%
• Tri Energy Co., Ltd.	3.0%
• Independent Power (Thailand) Co., Ltd.	3.6%
• Glow IPP Co., Ltd.	3.4%
• Eastern Power and Electric Co., Ltd.	1.8%

Table 5.1 Thailand's power generator (cont.)

Source	Production Share
Independent power producers (cont.)	
• BLCP Power Ltd.	6.9%
• Rayong Electricity Generating Co., Ltd.	1.6%
• Khanom Electricity Generating Co., Ltd.	3.8%
• Ratchaburi Electricity Generating Holding Plc.	11.3%
• Gulf Power Generation Co., Ltd.	6.2%
• Ratchaburi Power Co., Ltd.	4.2%
Small power producers	9.4%
External source	1.9%

Source: PTIT, 2008.

Table 5.2 Sources of electricity generation of EGAT

Source	Consumption (%)
Natural gas	70.0%
Lignite	12.6%
Imported coal	8.2%
Hydro	4.7%
Imported electricity	1.9%
Alternative energy	1.4%
Fuel oil	1.0%
Diesel	0.2%

Source: EGAT, 2010.

According to Table 5.2, EGAT consumed natural gas (70%) as the main source in power generation followed by lignite (12.6%) and imported coal (8.2%). However, according to the Department of Mineral Fuels of Thailand, proven and possible reserve of domestic natural gas were only sufficient to cover forecasted gas demand for the next 26 years whereas proven and possible reserves for coal would be available for an estimate of 110 years (GOT, 2009). For the future development of the power sector to meet the increasing demand, fuel mix adjustment towards the increase of natural gas might not be good to the country in term of resource reliance. Utilising domestic coal might be a good option but the fact that most coal reserves in Thailand were lignite with high sulphur content must be considered and properly managed. Accordingly, a power plant with coal-mixed fuel and retrofitted with advanced pollution control such as carbon capture storage might give a sound and promising solution for Thai power generation sector.

Alternative power generation technologies such as wind, hydro, nuclear, and solar are also of interest due to their low emissions during operation comparing to the conventional fuel fired power plant (Table 5.3). Over 80% of GHG emissions from the conventional fuel fired plant were the result of direct combustion of fossil fuel in the operational stage (Varabuntoonvit, et al., 2008) while nearly all the emissions of the alternative power plants occurred during the manufacturing and construction phase or routine maintenance (Parliamentary Office of Science and Technology (PST) of the United Kingdom, 2006).

Table 5.3 **Greenhouse gas emissions (GHG) for specific power plant type**

Power Plant Type		GHG Emissions (kg CO_2eq/kWh)	Source
Conventional			
Gas	Combined cycle	0.511010	(a)
	IPP	0.521090	(a)
	Steam turbine	0.681390	(a)
	Gas turbine	0.868993	(a)
Oil	Diesel	0.724000	(a)
	Steam turbine	1.291970	(a)
	Gas turbine	1.509000	(a)
Coal		1.125792	(a)
Alternative			
Wind	Onshore	0.004640	(b)
	Offshore	0.005250	(b)

Table 5.3 **Greenhouse gas emissions (GHG) for specific power plant type (cont.)**

Power Plant Type		GHG Emissions (kg CO_2eq/kWh)	Source
Alternative (cont.)			
Hydro	Run-of-river	0.005000	(b)
	Storage	0.01000 – 0.03000	(b)
	Thailand[a]	0.015100	(a)
Nuclear		0.005000	(b)
		0.016 – 0.055	(c)
Solar		0.035000	(b)
		0.022 – 0.049	(c)
Biomass	High density wood chip	0.025000	(b)
	Low density miscanthus	0.093000	(b)

[a]The data was for construction period.

Source: (a) Varabuntoonvit, et al. 2008

(b) Parliamentary Office of Science and Technology, 2006

(c) Fthenakis and Kim, 2007

Thailand had great potentials in developing renewable energy including wind, hydro, solar and biomass. However, solar, wind and hydro power were still at their early stages within the country. According to the Ministry of Energy (MOEN) of Thailand, only 0.064% of total potential for solar (or 32 MW out of 50,000 MW) and 0.069% of total potential for wind (1.1 MW out of 1,600 MW) were developed (GOT, 2009). Hydro power utilised only 8% of their total potential. The main barriers of the development were financial, institutional and legal constraints. The government needed to provide proper support in order to help overcome the barriers and scale up the use of the alternative energy.

Unlike other renewables, biomass was the most mature renewable energy in Thailand with 1,610 MW utilised from the total potential of 4,400 MW. The national plan was to increase biomass capacity to 3,700 MW by 2022. However, there were still 2 key barriers of biomass development. The first one was feedstock management. The past record showed that there was a competition for raw material resulted in the high costs of biomass power generation and risk of insufficient resources to operate the power plant at full capacity in the long run (GOT, 2009). The community acceptance was another barrier, which could obstruct the construction of power plants. This required the proper and sound environmental management of the biomass project.

5.2.1.2 Efficiency enhancement

The concept of efficiency enhancement was to optimise feedstock utilisation, increase portion of core product, and lessen byproduct as well as process gas emissions. Common areas for efficiency enhancement are:

- Enhance performance of energy conversion technologies, equipment and devices
- Enhance performance of process catalyst
- Utilise all byproducts to eliminate waste stream issues
- Improve overall energy management of production plant

Research and development (R&D) was the key sector for efficiency enhancement. Moreover, best practice sharing was also another good mean but the exchange of in-depth technological matters might be limited within the affiliated companies due to know-how confidentiality and competitiveness concern.

For the petrochemical industries, as suggested in Section 3.2 of Chapter 3, the energy efficiency enhancement of the onsite utility generation should be focused.

5.2.1.3 Innovation

Even many approaches were deployed in order to decrease carbon emissions; there was a need to innovate new technologies, products and/or measures towards the clean technology. Research and development (R&D) sector had an important role in bringing the promising innovation. Potential areas for the development in the petrochemical industries were:

- Improve industrial process monitoring and control
- New heating and cooling technologies
- New source of feedstock and energy
- Development of new low-carbon products

Many studies emphasised on the fourth area (EERE, 1999; Frontier Economics, 2009), the development of new low-carbon products, for example, the production from renewable sources such as plants and crops. Key challenges for the success of the development were:

5.2.1.3.A) Standard development and performance enhancement

Fossil-based petrochemicals have long been developed and their standards were greatly entrenched whereas the bio-based production was relative new and still lacked such quality standard. This created a barrier to successful competition with petrochemical products, particularly in areas in which direct competition occurred (EERE, 1999).

5.2.1.3.B) Reduction of cost per unit production

The current high cost of innovative products comparing to that of conventional products lessened their competitiveness. Lowering unit costs was critical for economically sustainable production. The government might provide supports through financial instruments such as loans. Moreover, there should be a proper regulation that allowed firm to benefit from the technology they exploit before that technology was back-engineering by other firms (Frontier Economics, 2009). Furthermore, it was important that consumers understood the true costs and values of alternative products and had the positive response to the price change.

5.2.1.3.C) Knowledge and wide range of professional experts involved

For many years, training of process chemists and engineers have been focused on hydrocarbon chemistry, with little consideration of the needs for processing plant-derived renewables (EERE, 1999). Besides the development of the knowledge, expertise in several disciplines such as chemistry, biotechnology, petrochemical technology, agriculture and marketing should be integrated.

5.2.1.3.D) Market perception

Renewable products were often viewed as inferior, especially when compared to high standard fossil-based products. It was true that current renewable resource chemicals did not compete well in certain areas (EERE, 1999). Enhancing the product performance was expected to help raise the market confidence.

Despite a desire for more environmentally friendly products, average consumer did not typically pay extra for “green” products. Thus, current progress in the use of renewables was based primarily on technology push. Increased market driving mechanism would create more powerful incentives for companies to invest in plant-based products, especially when industry acceptance was lagging due to entrenched petrochemical products (EERE, 1999). A major effort and sufficient resources were needed to boost product development, support mechanism, and market development in order to scale up the innovation activities.

In addition, an important area for other sectors that would support the low carbon production in the petrochemical industries was clean coal technology in the power sector. However, this required a clear and early signal from the government about investment in clean coal generation such as the support in carbon capture and storage (CCS) and phasing out the conventional coal generation (CCC , 2009).

5.2.2 Reduction of emissions release

5.2.2.1 Carbon capture and storage

Carbon capture and storage (CCS) is the technology that enables the continued use of fossil fuels while reducing emissions by capturing CO_2 emissions and storing or sequestering them in deep geologic formations for long periods of time (Klass, et al., 2008). Areas for potential CO_2 sequestration are oil and gas fields, saline aquifers and coal seams (Klass, et al., 2008). To achieve a significant climate benefit, CCS projects must store CO_2 underground for hundreds to thousands of years. However, this new technology has the potential health, safety and environmental risks, which should be well assessed before starting the project.

The CCS development in Thailand was just started. Key points to be included in the feasibility analysis were:

- *Technical feasibility*, which included geological formation assessment for site selection, capture technology, transmission and monitoring. The preliminary study indicated that potential site for CCS in Thailand was onshore carbonate reservoir due to their large underground storage. Offshore sandstone reservoir contained small pockets of pore volume, which might not be economically viable (PTIT, 2010).

- *Environmental, safety and health risk assessment*. The CCS technology involved potential health, safety and environmental risks, it was vital to assess all risks before starting the project. It is also important to increase public understanding towards the facts of the projects.
- *Economic viability*. The total costs of CCS consisted of 1) costs of constructing and installing equipment incurred at the beginning of the project, 2) costs of operating and maintaining the system and 3) costs of disposing of the equipment in an environmentally safe manner at the end of the project (Allinson, et al., 2009).

Finally, as the lifetime of CCS project was expected to be over hundreds or thousands of years, it is important to develop the mechanism to ensure the effective long-term stewardship and liability in all aspects, for example funding and managing CCS risks over the long term. The responsibility might be switched from private firms to public management in this regard (Klass, et al., 2008).

5.3 SUPPORT FROM THE GOVERNMENT

Besides regular laws and regulations regarding emissions control and management, the government issued a national strategic plan on climate change in 2008 in order to prepare the country to cope with the climate change impact and adapt to them. The plan comprised of 6 areas, which were:

- Capacity building on adaptation
- Research and development
- Institutional capacity building
- Public awareness and participation
- International cooperation
- Greenhouse gas (GHG) mitigation

The objective of GHG mitigation was to abate GHG emissions and improve production technology through the adoption of clean technologies in energy and production industries. Under the GHG mitigation plan, the government focused the efficiency improvement in 7 priority areas, which were (1) electricity production and use, (2) transportation, (3) alternative energy sources, (4) improved waste management and disposal practices, (5) industrial processes and efficiency, (6) agriculture, and (7) cleaner production technologies.

Although the fifth area, efficiency improvement in industrial processes, would directly provoke the emissions abatement in the petrochemical industries, the rest also indirectly related to the improvement of emissions reduction. For example, reducing emissions in the electricity, transportation and waste sector would decrease carbon expenditure for the petrochemical industries whereas research and development in alternative energy, agriculture and clean technology would lead to promising low carbon innovation to be adopted by the petrochemical industries.

After raising the awareness over the importance and urgency of carbon emissions reductions to get cooperation from all relevant sectors, in order to drive the emissions reduction and efficiency improvement in the industrial sector, the government could:

- Issue appropriate policies and measures e.g. energy policies and economic measures to ensure that the emissions mitigation is conducted in the most cost effective manner possible (DEFRA, 2004).
- Facilitate the implementation of clean development mechanism (CDM) in energy, industry, agricultural and waste sector.
- Support the development of GHG sequestration.
- Support the development of clean technology.

5.3.1 Energy policies

The government issued the national energy policies under the Tenth National Economic and Social Development Plan (2007 – 2011) with the intention to save foreign currencies from energy imports, decrease pollution caused by energy usage, increase energy efficiency, develop alternative energy sources, and reduce the vulnerability of Thai economic energy. The respective plans were listed in 4 areas (NESDB, 2007).

5.3.1.1 Intensity of energy development for greater self reliance

The aim was to create long-term energy security in the country by acquiring more energy supply sources domestically and internationally, for example support more investment in exploration and production (E&P) within the country and from neighbouring countries.

5.3.1.2 Promotion of alternative and renewable energy

The consumption of renewable energy under this plan was targeted to be 8.0%. This target required a sufficient conduct of research and development of alternative and renewable energy as well as feasibility study of its tendency towards conventional fuel replacement in terms of techniques, economical viability, environmental impact reduction and human resource capacity. The main sectors to be focused were transport sector and community levels.

5.3.1.3 Promotion of energy conservation and efficiency

The objectives were

1) *To decrease the proportion of energy consumption to GDP*. As stated in the Energy Conservation Act 1992, the energy intensity ratio was planned to reduce from 1.4:1 to 1:1. With this target, the amount of 10,354 kilotonne of oil equivalent (ktoe) or 12 % of commercial energy consumption would be reduced by 2011. The main sector to be focused was transportation with 21% reduction target, followed by the industrial, commercial, services and agricultural sectors, which together have 9% reduction target. Lastly, the residential sector was expected to reduce its emission intensity by 4%.
2) *To increase energy efficiency*. This could be done through mandatory measures and incentives, for example, controlling imports of foreign machinery and equipment with low efficiency in energy savings, or promoting investment for industries that create high economic value but use a small amount of energy

3) *To seek for participation of all sectors and creating consciousness in energy conservation*. Various forms of campaign could be utilised to achieve the objective e.g. a television advertisement to raise consumer's awareness of energy conservation or an energy saving project competition for students.

5.3.1.4 Promotion of clean development mechanism

The plan was to promote the energy production and consumption concurrently with the environmental conservation, which could be achieved under the clean development mechanism (CDM). More detail of CDM is described in section 5.3.3.

5.3.2 Economic measures

The government might use economic measures to support entrepreneurs to reduce GHG emissions and develop clean technologies. The economic measures could be categorised into 2 aspects: the demand-pull and the supply-push.

5.3.2.1 Demand-pull

The demand pull measures involved price signals such as carbon tax and cap-and-trade system (Schneider, et al., 2010). The concept of price signals was to set prices on carbon emissions, which reflects the damage caused by the emissions. Thus, it provided incentives to the use of less- or zero carbon intensive alternatives and the improvement of energy efficiency with the least cost abatement. However, price signal should be raised over time to reflect the increasing damage as the emission accumulates (Stern, 2008). Carbon tax and cap-and-trade systems were the key instruments under the demand-pull measures.

5.3.2.1.A) Carbon tax

The society might overlook the damage done by greenhouse gas emissions and unintentionally subsidise the use of conventional carbon intensive technologies. The lower- or zero carbon technologies were typically more costly than the conventional one, thus were at a cost disadvantage (Schneider, et al., 2010).

Carbon tax was an environmental tax levied on the use of carbon contained substances such as fossil fuel in direct proportion to their CO_2 emissions (Hoeller, et al., 1991). In general, burning hydrocarbons would emit a great amount of CO_2, while alternative or renewable substances with lower carbon content would release smaller amount of CO_2. Therefore, implementing the carbon tax was expected to help reflect the cost of damages caused by carbon emissions and increase the competitiveness of the cleaner technologies (Hoeller, et al., 1991). In other words, it would help protect the environment while earning revenue. Revenue earned from taxation could be used in the environmental treatment as well as the research and development of cleaner technologies (Schneider, et al., 2010). Or it could be recycled to the industries, which was expected to encourage emitters to reduce emissions as it would not increase their overall tax burden relative to other parts of the economy. Additionally, this approach could alleviate the initial impact of the scheme for entrepreneurs dealing with the cost increase, thus make the introduction of carbon smoothly (Stern, 2008).

If the carbon tax should be implemented in the future, the petrochemical industries would be affected directly from the consumption of fossil-based raw material and indirectly from the consumption of petroleum based power resulting in the price increase in petrochemical finished goods and the decrease of industrial competitiveness. This potential circumstance urged more research and development of alternative feedstocks as well as the development of non-combustion energy sources such as wind, solar, hydro and nuclear in the power sector.

Carbon tax could be implemented not only in the industrial sector but throughout the economy, especially in the dominant sources of greenhouse gases including energy and transport sectors. However, tax for different sectors should be well planned and might not be the same. For instance, the residential sector and industrial sector should not have the same tax rate as the industries had to stay competitive in the international market while household did not have this problem. Moreover, it was necessary to enhance the understanding of people about tax implementation and benefits as well as their own role in environmental sustainability.

5.3.2.1.B) Cap-and-trade

Cap-and-trade system or carbon trading was a market-based approach that helped meet the emissions reduction target by setting an emissions allowance so-called carbon credits, which would be allocated to firms in order to specify the amount of specific emissions they could discharge. Firms that emitted emissions below the permission might sell their extra credits to firms exceeding quotas. Thus, in theory, cap-and-trade system provided a flexible option for emission emitter who might struggle with the emissions reduction difficulties and a profitable means for those who could reduce their emissions easily. It was expected that the cap-and-trade system would incentivise long-term investment in low-carbon technologies (DEFRA, 2004).

Carbon trading in Thailand was still limited due to the lack of tangible government policy, the lack of specialist, and the lack of support from financial institutes. There was only one form of carbon trading, Over-the-Counter (OTC), which was occurred under the CDM. However, it is still questionable if the cap-and-trade would lead to sustainable environmental development as the emitter might choose to buy the extra credit and not attempt to reduce the emissions seriously. In addition, such commitment might worry the industries resulting in low participation in the scheme.

5.3.2.1.C) Green procurement

The government could play an important role in promoting the market of environmentally friendly products and services in 3 areas.

i) Public sector: In order to foster the market of environmentally friendly products and services, the government should take the lead in increasing more shares of green products in public procurement. A strong signal from the government through explicit action would raise public acceptance and confidence in products and respective measures. However, this might require regulatory amendment concerning purchasing by public sector bodies and certain utility sector bodies of contracts for goods, works and services.

ii) Private sector: The government could promote green procurement in private organisations through economic incentives such as tax reduction on the consumption of recycled materials. In addition, the government should also support respective knowledge sharing such as environmental management to stimulate the green supply chain in private sectors. Developing a database of green-labelled products would also ease the suitable product acquisition.

iii) General public: It was necessary to raise the confidence of people in the quality of green products. This could be done by issuing standards and quality guarantee for environmentally friendly products to be in conformity with the national or international standards.

As the petrochemical industries were the fundamental industries, supplying feedstocks for other industries, the green procurement measures, which mainly focused on finished goods, might not affect the petrochemical industries directly, but it would directly affect the derived industries such as the plastics industries. However, the increased consumption of more environmentally friendly finished goods would, in turn, lead to the increase of more environmentally production in the fundamental industries, and eventually the entire supply chain.

5.3.2.2 Supply-push

The supply push measures typically assisted the scaling up of low carbon technology development and deployment through financial support such as funding, subsidisation and loans to investors both in public and private sectors in order to overcome financial barriers. Box 5.1 provides definitions of funding, subsidisation and loans. Examples of potential areas entitled to the support were renewable and alternative energy, energy efficiency and industrial process advances, and emissions reduction technologies.

Box 5.1

Definitions of funding, subsidisation, and funding

Funding is to provide resources, typically in form of financing for a project, a person, a business, or any other public or private institutions. Most of environmental funds provide capital for environmental management investment. Source of funds could be the government, financial institutes, private sector, or other public organisations.

Subsidisation is to provide financial assistance paid to a business or economic sector. Most subsidies are made by the government in order to alleviate financial problems, for example, price subsidy is used to keep the price of the product at the competitive level.

Loan is a type of debt entailing the redistribution of financial assets over time, between the lender and the borrower. In a loan, the borrower initially receives or borrows an amount of money, called the principal, from the lender, and is obligated to pay back or repay an equal amount of money to the lender at a later time.

The government could provide supports by granting funds or subsidy to potential projects or could induce financial institutes to offer interest-free or low-interest loans to potential projects. However, there was a controversy over the drawbacks of subsidisation that it might not lead to the sustainable emissions reduction. For example, subsidising renewables projects did not lead to the increase of energy or carbon prices; thus the options to reduce emissions through energy efficiency improvement would not be exploited. Therefore, subsidies to individual projects would be acceptable as a way of bring down costs only if the projects were expected to be viable and competitive without the subsidies in the future (Schneider, et al., 2010). Other financial incentives were tax reduction for producers who used renewable, alternative or reused material, or reduction of importation tax on clean technology.

In addition, it was necessary that the government should also support the emissions reduction in other dominant emitters such as the power sector. One of the popular financial instruments to motivate the renewable energy development and deployment was feed-in tariff.

Feed-in tariff worked by guaranteeing a long-term premium payment electricity generated from renewable sources and fed into the grid. The government would fix the level of the tariff to be paid for each renewable technology and set the length of contract. The House of Commons Trade and Industry Select Committee in its report on local energy identified that "depending on its level, a feed-in tariff could be used to encourage the development of local energy" (Friend of the Earth (FOE), 2008).

5.3.3 Clean development mechanism

Kyoto Protocol required Annex I parties to lessen their GHG emissions to an average of approximately 5.2 % below their 1990 levels over the 2008–2012 period. The non-Annex I parties, on the other hand, did not have binding obligations. The clean development mechanism (CDM) was a cooperative mechanism established under the Kyoto Protocol aiming to assist the industrialised countries in meeting their greenhouse gas emissions commitment while promoting sustainable in the developing countries (UNFCCC, 2011). Under the CDM, Annex I parties were allowed to implement projects that reduced GHG emissions or removed GHG by carbon sequestration in non-Annex I parties in the addition to domestic emissions reduction actions. The reduced or sequestered amount of emissions from the project could be certified as carbon credits or certified emission reduction (CERs). These credits could be used by Annex I parties to achieve their GHG emissions reduction target. Participation under CDM was voluntary but must be approved by all parties involved.

Thailand, as a non-Annex I party, did not have emissions reduction obligation but could participate in the CDM as a host country. Promoting the implementation of CDM was expected to assist the country to advance the emissions mitigation, encourage the development of clean technology, and promote the sustainable development. Example of potential projects under CDM scheme was the replacement of carbon intensive fossil fuel with renewables such as wind, hydro, solar or biomass in the power generation sector. Another example was methane recovery in wastewater and municipal solid waste treatment combined with utilisation of recovered methane in the heat and electricity generation.

The development of small CDM projects in Thailand, however, was facing obstacles especially in the lack of project development expertise and financial shortage. The government therefore should provide the sufficient support on these aspects.

5.3.4 Greenhouse gas sequestration development

As discussed in section 5.2, the government should provide a clear and early signal about the direction of greenhouse gas emission sequestration development, for example, the continuity of coal-fired power generation, which would require CCS retrofitting, or the plan to implement CCS at the industrial emissions sources.

5.3.5 Clean technology development

The government needs to ensure the clean production in the industrial and service sectors and extend the results of clean production as well as develop personnel for clean technology fields (NESDB, 2007). The clean technology that Thai government was focusing on was in the energy sector, such as wind and nuclear generation. It was suggested that creating incentives such as carbon price underpin, low-carbon obligation and emissions performance standards would drive the development of low-carbon technologies (CCC , 2009).

Furthermore, in order to make new technologies sustainable, the government needs to design the policies that create market for the new technologies to be mature, accepted and successfully employed. The key is to set in motion a process of self sustained growth, driven by dynamic learning and scale effects, where cost reductions generates market growth that, in turn, generates investments and learning that lead to further cost reductions (Stern, 2008).

5.3.6 Other supportive activities

Besides the above policies and measures, there are other supportive activities the government should consider in order to support the low carbon development.

5.3.6.1 Development of carbon emissions database and benchmarking

A carbon emissions database should elaborate the emissions current status and trend of each emissions source. With reliable and thorough detail, the policy makers might utilise it as a source of information to set directions, strategies and policies that are suitable for specific circumstances. As data required for the database development are considered as confidential, the government, or otherwise, the neutral organisation should be the focal point in collecting, compiling and analysing the data in order to prevent the disclosure of confidential and sensitive data. The database could also be used in benchmarking objective, which would be beneficial to the emitters in term of green competitiveness awareness; thus would consequently encourage the development of cleaner operations. However, the level of data access should be varied depend on the confidentiality of the data. For example, the individual data should be accessed only by the database developer and by respective data provider, whereas the data of the overall sector could be publicly accessed.

Other database and benchmarking that should also be developed are an energy performance database and an energy consumption database.

5.3.6.2 Standard, guideline and labelling

The government should develop minimum standards for energy saving, energy consumption, and carbon emissions for products and services. By setting up the standards, the quality of products and services would be ensured and the research and development sector would have the idea of which directions they should pursuit. In addition, the government should promote the development of products above the defined minimum standards. Although performance standards are likely to enhance cost efficiency they should be carefully implemented. For instance, performance standards are in general preferable to technology specific standards. There is a risk that the standard itself freezes at the same level for too long. Standards might become impediments to a more dynamic development. An alternative might be to introduce dynamic efficiency standards that mirror the best available technology with a time lag that depends on the sector (Schneider, et al., 2010). By introducing dynamic standards, it is possible that the entrepreneur with poor environmental performance would be phased out.

Correspondingly, the government should also develop guidelines for implementation, for instance, energy management standard and guidelines, energy monitoring and management guideline for improving energy efficiency, energy audit tool for identifying energy-saving opportunities and energy performance assessment (EACI, 2009). Moreover, the government could help raise the confidence of consumer over green products through labeling the environmentally friendly guaranteed products. Or the government could promote carbon footprint label informing carbon emissions generated in order to give consumer information for decision making when purchasing products and services.

5.3.6.3 Partnership development

As the transition to the low-carbon community required collaboration from various sectors including the government, businesses, financiers, international and national organisations and representatives of civil society in order to make it successful, the government, or other neutral parties should develop such partnership and provide floors for dialogue, exchange and knowledge sharing.

5.3.6.4 Awards

Awards would present a good image for entrepreneurs and thus help them increase their green competitiveness. The government should organise awards granting to entrepreneur with excellent environmental performance in order to inspire the enhancement of emissions management and clean technology development.

5.3.6.5 Human resource development

The government should organise training and capacity building activities in relevant areas such as energy management. The activities include academic education, training, seminars, and best practice and knowledge sharing. Both national and international experts might be required.

Finally, above all measures, policies and strategies, the government should be a good example in the emissions reduction by taking a lead in cutting their own emissions. An explicit action of the government would emphasise the seriousness of the plan and would encourage the cooperation from every sector.

5.4 CONTRIBUTION FROM OTHER SECTORS IN CARBON EMISSIONS REDUCTION

In order to create the low-carbon economy, contribution of every sector was very important. It was necessary to prioritise which sector should be decarbonised first. This could be done by considering historical data.

The national greenhouse gas inventory for the year 1994 showed that the major contributors to GHG emissions were electricity sector, followed by agriculture, and land use change and forestry (Figure 5.4.). The industrial process was at the forth rank and the waste sector was at the fifth rank.

In addition, when considering emissions from fuel combustion (Figure 5.5), emissions from energy generation, transport sector, and industry and construction were the three top-ranked contributors. Data in Table 1.1 of Chapter 1 underlined that electricity generation was the largest contributors to Thailand's GHG emissions, followed by transport sector and manufacturing sector. The sum of these three sector accounted for about 90% of the total emissions in the year 2002 and 87% in the year 2006. Residential and commercial sector also contributed in the national GHG emission, but with a small portion 3.36% and 7.75% in the year 2002 and 2008 respectively.

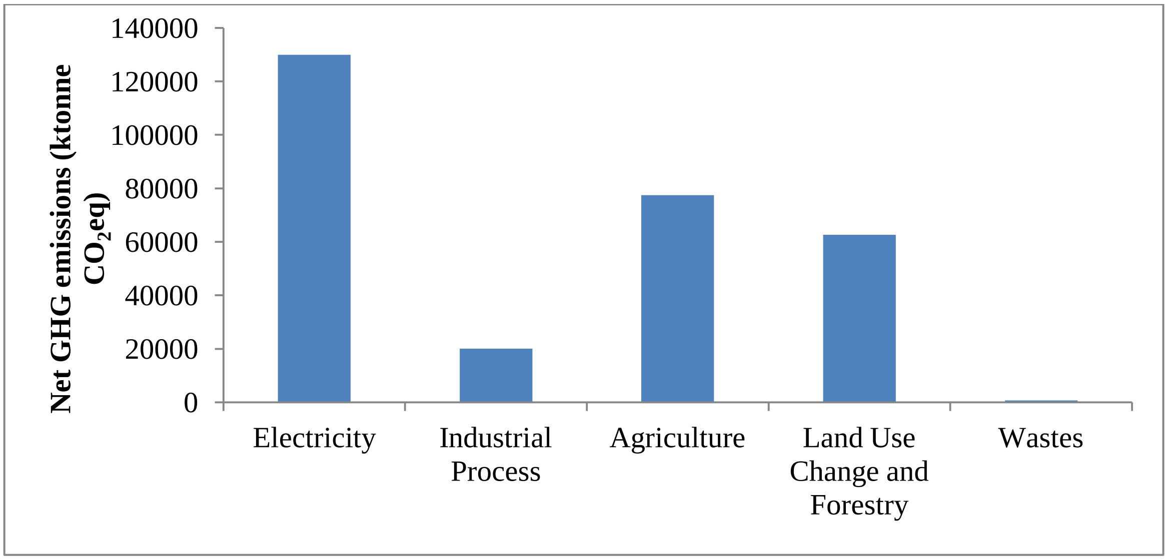


Figure 5.4 **Thailand's net greenhouse gas emissions (ktonne CO_2eq) of the year 1994** (MSTE, 2000)

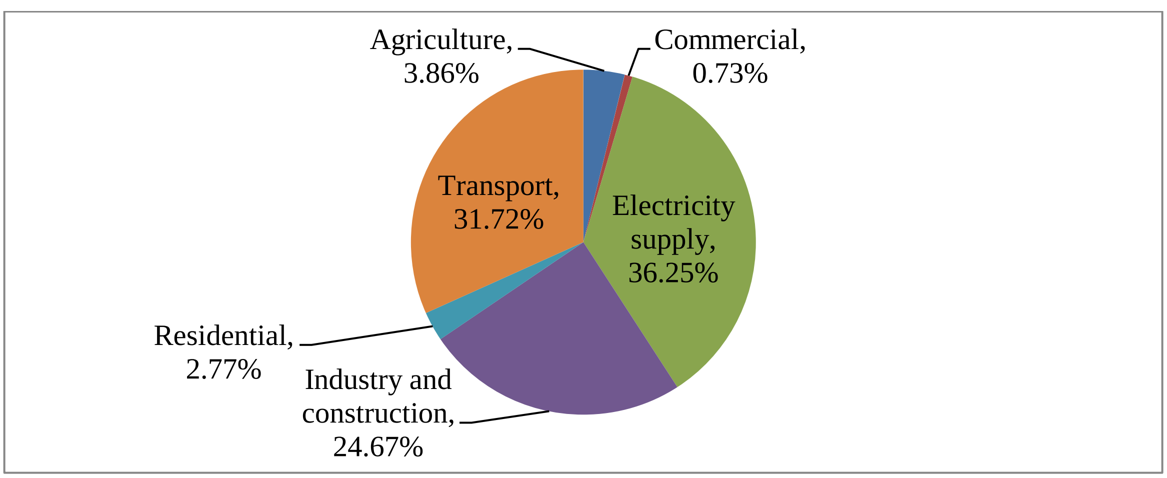


Figure 5.5 **Thailand's greenhouse gas emissions from fuel combustion, 1994** (MSTE, 2000)

Table 5.4 shows greenhouse gas emissions of major industrial process in the year 1994. Almost 16,000 ktonne of CO_2, 0.3 ktonne of CH_4, and 2,513 ktonne of NMVOCs were emitted from the various manufacturing processes in these industries (Table 5.4), the cement industries emitted the highest CO_2 emissions (90%), followed by the lime (6%) while the food and beverage sector was the largest source of NMVOC. The GHG emissions from petrochemical industries were comparatively very low although this might be due to a lack of CO_2 emission data.

Table 5.4 Greenhouse gas emissions of major industrial processes, 1994 (ktonne)

Industry	CO_2	CH_4	NMVOC
Cement	14,920.0		
Glass	63.6		2.2
Lime	918.0		
Pulp and paper	49.3		
Iron and steel	19.5		NA
Petrochemicals	NA	0.3	4.7
Food and Beverage			2,505.7

Note. NA means not available.

Source: Ministry of Science, Technology, and Environment (MSTE) of Thailand, 2000.

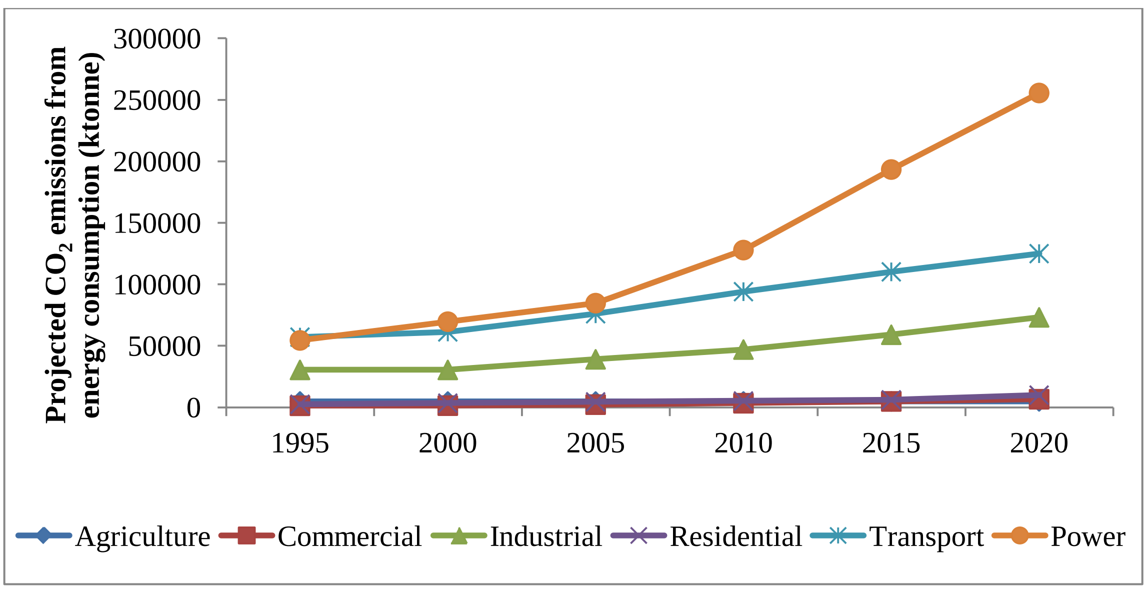


Figure 5.6 Projected CO_2 emissions from energy consumption in different sectors (MSTE, 2000)

Figure 5.6 illustrates the trends of CO_2 emissions from energy consumption in different sectors. The emissions of power sector were expected to increase substantially and would be more than 400% higher than the 1995 level. The transport sector was expected to be the second largest emissions contributor.

Therefore, the first two prioritised sectors requiring the national attention for emissions reduction would be energy generation and transport sector. The industries, particularly cement, food and beverage, and lime industries should also be focused upon. Other sectors, even with minor emission share, could also contribute in the attempt of emissions reduction for the sustainable development of the country.

5.4.1 Main success factors

5.4.1.1 Clear signal from the government

The government should provide a clearest possible signal on the development of a low-carbon community. It could be done by issuing laws and regulations, directions and measures, and by developing standards of low-carbon technology, products and services.

5.4.1.2 Attention of senior staff

It is necessary to bring the issue to the attention to the corporate senior staff in order to gain full support from them. The issue includes the importance of emissions abatement, financial return and payback period, and prospective obstacles.

5.4.1.3 Public awareness

Technology and standards alone could not deliver the full potential for emissions reduction, it requires understanding and buy-in at all levels of society. It is necessary to raise a greater awareness of the issue and its links to people's routine activities such as energy use. This could be done by using targeted campaigns and drivers that are relevant to each audience (DEFRA, 2004). The effectiveness of these campaigns might be enhanced by the development and introduction of an overarching theme or message, promoting a common background and justification. The message should clearly link everyday activities with the climate change results and mitigation measures. It is expected that the awareness would result in changes in behaviour and thus stimulate the low-carbon supply chain. Moreover, a network among public sector, private development organisations, private sector, community, localities and scholars should be set up to create genuine social drive for the operations (NESDB, 2007).

5.4.2 Areas for emissions mitigation in other emissions sources

5.4.2.1 Energy sector

Decarbonisation of energy sector was the first priority the country should achieve. As suggested in section 5.2, the promising development direction for the energy sector could be addressed in 3 areas. First, the power plant might continue utilising the same fuel-mix ratio with about 13% consumption on domestic coal for the resource liability reasons (Table 5.2). But such plant should be retrofitted with higher advanced pollution control and management. Second, the utilisation of renewable fuels such as biomass should be increased. Finally, alternative power sources such as wind, hydro, nuclear and solar should be developed. A combination of 3 approaches should even result in a better emissions reduction performance. However, this required clear and early signal from the government about future power investment and market arrangement to support the low-carbon power generated.

5.4.2.2 Agriculture

The reduction of GHG emissions in agricultural sector could be done through soil and livestock measures. Examples of activities to reduce GHG emissions in rice cultivation are irrigation management, nutrient management and introduction of new cultivars (Ravindranath, et al., 2002). Examples of activities to reduce GHG emissions concerning livestock management are diet quality and nutrient balance improvement and feed digestibility enhancement by treatment of straw using ammonia (Ravindranath, et al., 2002).

5.4.2.3 Land use change and forestry

Based on the national policy on forest conservation and reforestation, it was expected that carbon sequestration rate would increase, resulting in lower net emissions (MSTE, 2000). Reforestation and plantation activities would help raise the amount of carbon removed from the atmosphere.

5.4.2.4 Transport

Transport sector was a major consumer of imported fossil fuels and a big contributor to GHG emissions (GOT, 2009). Over 70% of petroleum products were consumed by the transport sector, and most of these were derived from imported crude oil. The emissions from transport sector could be reduced through higher carbon efficient vehicles.

5.4.2.5 Other industries

Emissions reduction in other industries could be achieved by energy efficiency enhancement, increase of renewable resource penetration and boost in low-carbon research and development.

5.4.2.6 Other sectors

Residential and non-residential building, especially in urban area, even with the relatively small emissions share to the national emissions, should employ the energy efficiency improvement in order to help reduce the national emissions. Moreover, energy-efficient street lighting programmes was also recommended (GOT, 2009).

5.4.3 Consumers

Behaviour change is a key challenge in the national emissions reduction. People need to realise that resource base is a public treasure and everybody would equally receive benefits from it as well as take responsibility for it (NESDB, 2007). The examples of behaviour that help create low carbon society are energy conservation, and procurement of sustainable products and services.

5.4.4 Academia and environmental third party

Main roles of academia and the environmental third party in the creating of low-carbon economy are:

5.4.4.1 Educating and capacity building

The academic sector should provide education to create knowledge and maintain academic impartiality (NESDB, 2007). In addition, they should provide academic advice in order to help both public and business sector respond to the government's environmental measures and help them understand the risks and capture the opportunities in energy efficiency and carbon management (DEFRA, 2004). They should also disseminate the existing good/best practice in the respective areas.

5.4.4.2 Research and development

Academia should coordinate business sector in research and development of the low carbon innovation, clean technology, and materials technology in order to save resources and energy as well as to help reduce pollutions (NESDB, 2007).

5.4.4.3 Supporting the database set up

As the energy and environmental data are perceived as confidential, the credible third party would play an important role in collecting the respective data and develop the environmental database for the benefits of benchmarking and policy making.

5.4.5 Financial institutes

Financial institutes play an important role as financial sources for respective projects. However, financial institutes might be reluctant to provide such support because they are uncertain about the likelihood of success of the projects. As suggested in section 5.1.6.2.B, examples of economically successful cases would help raise the confidence of the financial institutes over the future of low-carbon technology ventures. In addition, the government or the academia or the environmental third parties could assist in providing a good understanding of the importance of the projects and the essential of financial support.

5.4.6 Mass media

Mass media should assist in publicising the models of the resource base and environment conservation and management of balance and sustainability as well as news, information and knowledge to raise knowledge, understanding and consciousness about natural resources and environment conservation (NESDB, 2007).

5.5 PROPOSED IMPLEMENTATION PLAN

The implementation plan to mitigate carbon emissions in petrochemical industries was proposed in Table 5.5. The plan was divided into 3 phases: short term, medium term, and long term. Short term plan suggested activities that could be started at once, while medium and longer term need a certain of time to achieve goals.

The possibly most important driver of carbon emissions mitigation in Thailand was that the government must provide clear and early signal through their policies and regulations. However, some emissions mitigation activities could be performed without waiting for such signal, for example, fuel switching and efficiency improvement. On the other hand, it was more appropriate to wait for the government policies before execute some activities, particularly ones with high cost, i.e. CCS.

Table 5.5 Proposed Implementation Plan

Item	Short Term (Year 1 – Year 5)	Medium Term (Year 6 – Year 10)	Long Term (Year 11 – Year 20)
1. Government			
1.1 Regulation	1.1.A.1 Develop national GHG management plan 1.1.A.2 Develop national plan for the development of renewable energy, alternative energy, and new technology. 1.1.A.3 Foster the development of renewable energy[1)] 1.1.A.4 Certify projects qualified for clean development mechanism	1.1.B.3 Foster the development of alternative energy[1)]	1.1.C.3 Foster the development of new technology[1)]
1.2 Carbon capture and storage (CCS)	1.2.A.1 Investigate CCS potential in Thailand 1.2.A.2 Conduct feasibility studies 1.2.A.3 Develop geological storage atlas and national plan for CO_2 storage	1.2.B.1 Conduct pilot CCS project 1.2.B.2 Develop infrastructure for CCS	1.2.C.1 Implement CCS project

Table 5.5 Proposed Implementation Plan (cont.)

Item	Short Term (Year 1 – Year 5)	Medium Term (Year 6 – Year 10)	Long Term (Year 11 – Year 20)
1. Government			
1.3 Others	1.3.A.1 Develop national GHG inventory • Develop local emission intensity • Collect appropriate activity data • Develop estimate method to higher tier. • Develop techniques in GHG emission forecast		
	1.3.A.2 Human resource development program		

Table 5.5 Proposed Implementation Plan (cont.)

Item	Short Term (Year 1 – Year 5)	Medium Term (Year 6 – Year 10)	Long Term (Year 11 – Year 20)
2. Research and development sector[2)]			
	2.1.A.1 Increase competence of renewable energy		
	2.1.A.2 Develop alternative energy i.e. biomass to oil, hydrogen fuel	2.1.B.2 Increase competence of alternative energy	
	2.1.A.3 Develop new technology • Plant genetic engineering for the production of appropriate feedstock • High performance multifunctional catalyst • Hydrogen energy • Advanced technologies for energy conservation, electricity production and consumption		2.1.C.3 Increase competence of new technology
	2.1.A.4 Develop new low carbon product	2.1.B.4 Increase competence of new low carbon product	

Table 5.5 **Proposed Implementation Plan (cont.)**

Item	Short Term (Year 1 – Year 5)	Medium Term (Year 6 – Year 10)	Long Term (Year 11 – Year 20)
3. Individual plant			
3.1 Low carbon material and energy	3.1.A.1 Switch to alternative low carbon raw material 3.1.A.2 Fuel adjustment towards low carbon fuel (i.e. natural gas) and renewable energy	3.1.B.2 Fuel adjustment towards alternative energy	
3.2 Efficiency enhancement	3.2.A.1 Improve process to utilise all byproducts to eliminate waste stream 3.2.A.2 Improve energy management of production plant 3.2.A.3 Enhance performance of energy conversion technology 3.2.A.4 Switch to higher efficient technology currently available		3.2.C.4 Switch to new technology

Table 5.5 **Proposed Implementation Plan (cont.)**

Item	Short Term (Year 1 – Year 5)	Medium Term (Year 6 – Year 10)	Long Term (Year 11 – Year 20)
4. Utility generation unit			
4.1 Low carbon material and energy	4.1.A.1 Switch to alternative low carbon material and energy i.e. natural gas 4.1.A.2 Fuel adjustment towards low carbon fuel (i.e. natural gas) and renewable energy		
4.2 Efficiency enhancement	4.2.A.1 Improve energy management of production plant		
	4.2.A.2 Enhance performance of energy conversion technology		
	4.2.A.3 Switch to higher effective technology currently available		4.2.C.3 Switch to new technology
4.3 Carbon capture and storage			4.3.C.1 Implement CCS

[1)] Fostering the development of renewable energy, alternative energy and new technology could be done through policies, measures and incentives.

[2)] Research and development sector could be in academic sector, environmental third party or in individual petrochemical company.

5.6 CONCLUSION

The success of carbon emissions reductions required contributions from every sector across the nation in both amount of emissions cut and other forms of support. It was not necessary to decrease the emissions in every sector equally but rather to prioritise the urgency and quantity based on current and projected emissions share, and ease and likelihood of success. In this regard, section 5.4.2 suggested that, the electricity generation and transport sector should be the first two priority sectors in Thailand to be focused upon. The industrial sectors, particularly cement, food and beverage, and lime industries also deserved attention. Other sectors, even with the small emissions share should also contribute in the attempt of emissions reduction.

The petrochemical industries in Thailand, as a matter of fact, emitted a lower amount of carbon than many other sectors in Thailand or other countries did and it had no carbon emissions reduction obligation. But in order to prepare themselves for the potential stringent laws and regulations, the industries should advance their emissions abatement as well as develop the promising low-carbon technologies. The emissions reduction could be achieved in 2 ways: the reduction of emissions generation or emission intensity and the reduction of emissions release. The first one involved the shift to less- or zero- carbon intensive material and energy, the efficiency enhancement and the development of cleaner technologies whereas the latter one focused on the carbon capture and storage (CCS) retrofitting into the current production technology.

The government could stimulate the low carbon economy through various policies and measures, for example, carbon pricing could make short-term emissions reductions; promote alternative and renewable energy development under the energy policies, promote the energy efficiency enhancement under clean development mechanism; and encourage the clean technology development would lead to the long term improvement. Nevertheless, as the petrochemical industries highly consumed fossil fuel, which was carbon intensive; thus, they were likely to be sensitive to the tentative policies and measures e.g. carbon pricing. The prolonged capital infrastructures investment was already in place, thus a clear and early signal from the government was critical to them. In addition, the government should play an important role in raising awareness of the issues; developing an emissions database; benchmarking; developing standards;

environmental labelling; strengthen the collaboration of all sectors; and enhancing capacity building.

Some other policies might have an effect on carbon emissions. For example, some emissions control policies could lead to carbon emissions reduction as a co-benefit; while some policies such as promoting the use of coal in the power generation to enhance energy security could result in the increase of carbon emissions. Policy markers should ensure that in the process of solving one problem they would not create or contribute to others unwittingly. For instance, with a higher carbon price, the profitability of well-performing biomass systems (e.g. forest residues used for heat generation) would increase, but this might drive up food prices and cause biomass plantations to supplant natural forests and land held by poor farmers in developing countries with poor property rights (Schneider, et al., 2010).

CHAPTER 6

THE CASE STUDY

CHAPTER 6

THE CASE STUDY

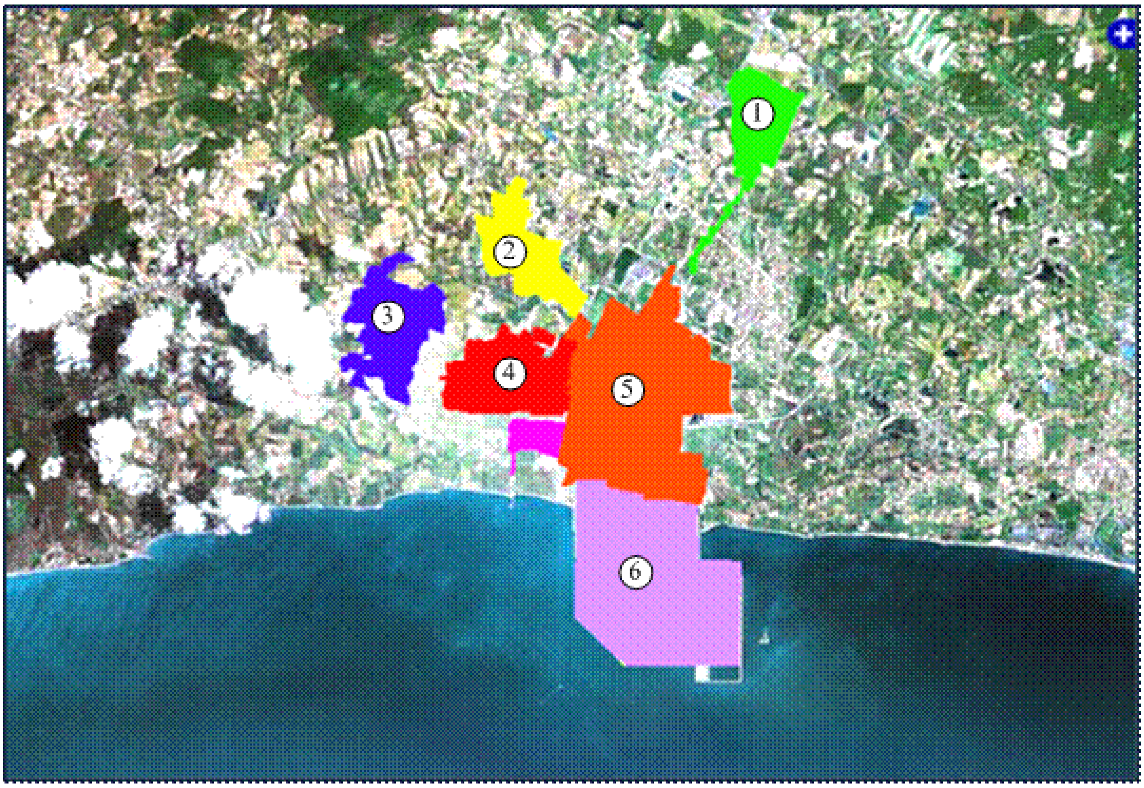
6.1 INTRODUCTION

Despite the result of this study that shows the relatively low carbon emissions of the petrochemical industries, the industries had to confront the most critical environmental and social issues at the country's major industrial sites, Map Ta Phut.

Map Ta Phut Industrial Estate (MTPIE) was established in 1989 as state enterprise. It is situated in Map Ta Phut district of Rayong province, eastern Thailand (Figure 6.1). The location borders the gulf of Thailand and is close to Bangkok (180 km.) and Suvarnabhumi airport (120 km.). With this locational advantage, i.e. close to sea, the capital and a major port, the country aimed to develop MTPIE to be a modernized industrial complex and logistic base under the National Eastern Seaboard Development plan (MTPIE, 2010). Major industries situated in MTPIE were petrochemical, chemical, iron, metal and steel, oil refineries and power plants. Besides MTPIE, there were other industrial estates located in Map Ta Phut district, namely RIL, Hemraj, Asia, and Pa Daeng Industrial Estate (Figure 6.2). The total factories situated at these 5 industrial sites were 138 and the total investment value was 910 billion Thai Baht (THB) or 13.57 billion Pound Sterling (GBP)[1] (Yindepit, 2009). By developing the industries as the cluster, the entrepreneurs enjoyed the competitiveness enhancement through the increase of production efficiency and reduction of transportation cost. Recognising the importance of economical contribution of the industries, the government fostered the development of the petrochemical industries under the third master plan (2004-2018), which aimed to support domestic industrial growth and move the country towards specialty export earnings (Chuchottaworn, 2009). Concurrently, the government issued a number of environmental laws and regulations to mandate any project or activity that had a potential environmental impact in order to conserve the environment. The laws and regulations that are relevant to the petrochemical industries are listed in Appendix C.

[1] An average exchange rate of the year 2002-2009: 67.0838 THB per GBP (BOT, 2011).

<u>Figure 6.1</u> Map of Thailand



1: RIL Industrial Estate
2: Hemraj Industrial Estate
3: Asia Industrial Estate
4: Pa Daeng Industrial Estate
5: Map Ta Phut Industrial Estate
6: Map Ta Phut Deep Sea Port

Figure 6.2 Industrial sites located in Map Ta Phut district

Besides these laws and regulations, the government enforced the use of Environmental Impact Assessments (EIA) under the Enhancement and Conservation of National Environmental Quality Act (1981) as a tool for environmental planning and management including environmental risk mitigation. The EIA process also helped screen the economic and environmental sound projects for the benefits of the national sustainable development.

6.2 THE BEGINNING OF THE PROBLEM

In spite of the industries' compliance with the environmental laws and regulations, nearby communities found that the industrial operations had negative impacts on the environmental, health and social aspects. The problem started in 2000 (Figure 6.3), in which the communities noticed a nuisance odour from petrochemical plants and refineries. Odour controlling at sources was the measures at that time. The nearby school was then relocated to outside problem area to avoid the possible repetition. Later in 2005, the eastern region of the country experienced a severe drought. The problem of water allocation between communities and industries was triggered but was eventually solved by acquiring water from other regions. Shortly after that, the communities intensely complained about the air quality and found the supportive information showing the possibility of carrying capacity of particular substances being exceeded when all plants were working at their full capacities, particular problems were noted with: sulphur dioxide, nitrogen oxide and particulates. They also claimed that the emissions of volatile organic compounds (VOC) from the petrochemical industries caused the serious illness among the population and the cancer rate in Rayong province was the highest in the country. Other problems such as water contamination and illegal solid waste disposal were also raised. Consequently, a group of Rayong villagers and the anti-global warming association filed a petition to Rayong Administrative Court and the Court finally declared Map Ta Phut a pollution control zone in 2009. This declaration demanded relevant authorities to closely monitor environmental quality and to prepare a pollution reduction plan if necessary (The Nation, 2010).

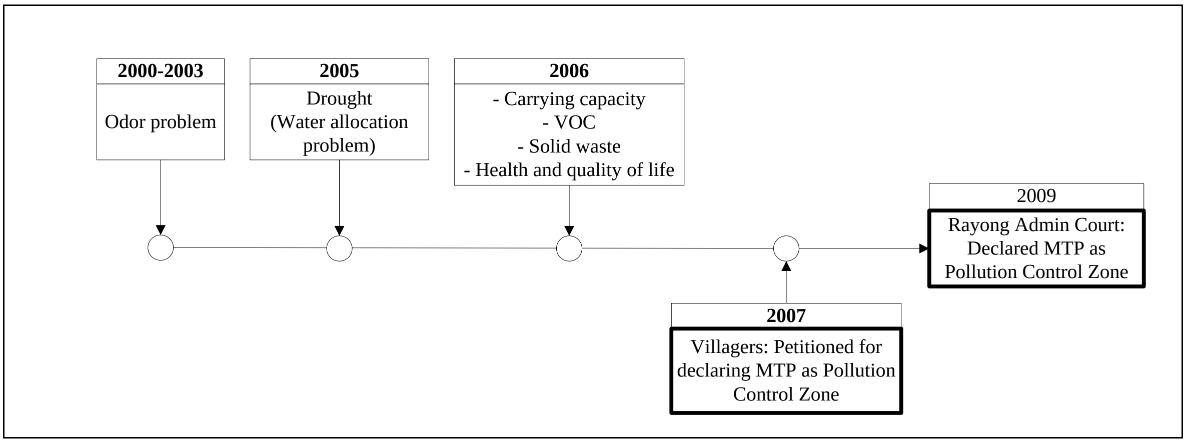


Figure 6.3 The significant events at Map Ta Phut district

6.2.1 The scientific fact

Although the Court had already declared Map Ta Phut as the pollution control zone, it was still uncertain as to the scientific basis to the claim of pollution from the works.

6.2.1.1 The carrying capacity

It was claimed that it was theoretically possible that acceptable levels of sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and particulate (PM10) could be exceeded if all plants operated at their full capacities; however, the historical data showed that the monitored amount of such pollutants were much lower than their respectivie national standards and did not exceed the capacity allowance (Table 6.1). Nevertheless, it was noted that over 80 percent of the total emission of SO_2 and NO_x were from power plants (Yindepit, 2009).

Table 6.1 Rayong air quality status as in 2008

Pollutant	Station	Standard	Monitored values
SO_2	Ampur Muang	300 ppb (Average 1 hour)	0-70 ppb
NO_x	Field Crop Research Center	170 ppb (Average 1 hour)	6-50 ppb
PM10	MTP health station	120 $\mu g/m^3$ (Average 24 hours)	9.7-61.9 $\mu g/m^3$

Source: PCD, 2010.

6.2.1.2 Emissions of volatile organic compound and its relation to the cause of cancer among Rayong villagers

The villagers claimed that emissions of volatile organic compound (VOC) from the petrochemical industries were the major cause of the serious illness in the village, i.e. cancer among them. In response to the accusation, there are 3 points to be made.

6.2.1.2.A) The emissions of volatile organic compound

There were 3 VOC chemicals the annual average of which exceeded the national standard, these were benzene, 1,3-butadiene, and 1,2 dichloroethane. However, it was noted that the national annual standards of these chemicals were more stringent that those of other developed countries such as Japan and the United Kingdom. Additionally, the maximum concentration of benzene and 1,3-butadiene in ambient air of Bangkok were found higher that those in Rayong. Table 6.2 shows the maximum VOC concentration in Rayong comparing to that in Bangkok and to the standards themselves.

Table 6.2 Rayong's volatile organic compound status in 2008 (unit: μg/m³)

Pollutant	Max Concentration		Standard		
	In Rayong	In Bangkok	Thai	Japan	UK
Benzene	3.00	5.20	1.70	3.00	5.00
1,3-Butadiene	0.53	0.73	0.33	2.50	2.25
1,2-Dichloroethane	5.90	0.29	0.40	1.60	4.80

Source: PCD, 2010.

There were 6 other VOCs monitored in Rayong's atmosphere namely vinyl chloride, chloroform, dichloromethane, trichloroethylene, 1,2-dichloropropane and tetrachloroethylene. However, the concentrations of these chemicals were still in compliance with the standards.

6.2.1.2.B) The cancer rate:

The cancer rate that the plaintiff used in the trial was calculated from the division of registered cancer cases at the hospitals in the province with the number of registered population, which was much lower than actual population due to an existence of non-residence or unregistered population from other provinces. This was the reason why the result was on the high side. Also, for the scientific diagnosis, the age-standardised incident rate (ASR) should be applied in order to observe the actual cancer rate.

Age-standardised cancer incident rate (ASR) is a summary measure of a rate that a population will have if it has a standard age structure, expressed per 100,000 populations. Standardisation is necessary when comparing several populations that differ with respect to age because age has powerful influence on the risk of cancer (PTIT, 2009). With the ASR concept, the National

Cancer Institute reported that the cancer rate in Rayong was not the highest in the country as shown in Table 6.3 (PTIT, 2009).

Table 6.3 Age-standardised incident rates (ASR) of cancer in selected provinces in Thailand

Province	Male		Female	
	Cases 1998-2000	ASR 1999	Cases 1998-2000	ASR 1999
Udon Thani	3,292.00	242.00	2,815.00	158.40
Lumpang	2,042.00	160.70	2,050.00	148.90
Khon Kaen	3,567.00	167.60	3,281.00	129.70
Chiengmai	3,170.00	138.70	3,760.00	152.50
Rayong	719.00	122.80	806.00	115.20
Bangkok	8,466.00	117.40	10,907.00	116.00
Songkhla	1,667.00	104.50	1,822.00	98.90
Nakhon Phanom	874.00	107.70	833.00	92.60
Prachuap Khiri Khan	415.00	74.70	514.00	77.60
Thailand	94,746	127.7	101,034	125.5

6.2.1.2.C) The relation of VOCs from the petrochemical industries and the cancer cause

There were several factors causing cancer in human ranging from internal factors such as age, immune system and heredity to external factors such as individual's lifestyle; duration and level of carcinogen exposure. Some VOCs were classified as carcinogenic and could be found in many activities, for example: transportation; painting and coating; dry cleaning; solvent usage; pesticide usage; smoking and open burning. Confirming a direct relation between cancer and VOCs emissions from specific petrochemical plants without analysing all potential factors is not a scientific opinion. Furthermore, exceeding screening level did not mean that people were already in danger. The screening level was the level where further investigation was needed to confirm longer term exposure risk and to identify mitigation measures. To develop cancer from carcinogenic chemicals, one must have experienced consistent long term exposure and at high concentration (PTIT, 2009).

6.2.2 The local environmental plan for pollution control zone

After Map Ta Phut and its vicinities were declared as the pollution control zone, the government together with the private sector developed an environmental improvement plan to reduce and control the pollution. The result of the plan is shown in Table 6.4 (Industrial Estate Authority of Thailand (IEAT), 2010). Nevertheless, the pollution reduction and control was not a one-off action, but should be conducted continuously for the good quality of life.

Table 6.4 Mitigation achievement during April 2008 – March 2009

Item	Unit	Target	Achievement		
			March 2007 – March 2008	April 2008 – March 2009	April 2009 – March 2010
VOCs	Points[a]	100	99	100	100
NO_x	% of max actual	10-20%	23.1%	21.5%	21.4%
SO_x	% of max actual	10-20%	25.6%	28.5%	30.7%
Wastewater	m^3 per year	700,000	2,106,994.4	765,163.9	1,691,641.7
Solid waste	tonne	461,974.2	414,586.4	354,843.7	593,415.7

[a]Target points for VOCs reduction were those from significant sources such as pump, open drain, leakage and spillage.

6.3 THE SECOND CONFLICT

After the declaration of the Pollution Control Zone, the development of the industries in MTPIE had to face another hurdle when the villagers and the anti-global warming association filed another petition to the Central Administrative Court on government agencies' violation of the article 67 of the new Constitution implemented since 2007. The Article 67 of the Constitution states that "any project or activity, which may seriously affect the quality of the environment, natural resources and biological diversity shall not be permitted, unless its impact on the quality of the environment and on health of the people in the community have been assessed; public hearing and stakeholder consultations have been managed; opinions of an independent organisation, which consists of representatives from private environmental and health organisations and that from higher education institutes in the field of environmental, natural resource or health management have been obtained prior to the operation of such project or activity" (Central Administrative Court, 2009). Although these requirements took effect immediately after the Constitution was proclaimed, neither organic laws nor associated regulations such as the health impact assessment guideline, or the provision of independent organisation was issued. This was due to the domestic political crisis and the unstable cabinet of a government, which decelerated the regulatory proceeding. Nonetheless, the lack of clear laws and regulations prevented entrepreneurs from complying with the Constitution. The previous practice in this similar case was that the entrepreneur could legally prolong their business until the organic laws were announced. However, under the new Constitution, the Court clearly stated that "the rights of individuals under Article 67 of the charter are protected. The fact that there are no laws yet to set the regulations, conditions and methods of exercising such rights is not a basis for a state agency to use as an excuse to deny them the protection" (The Nation, 2010). This resulted in the Court decision to suspend 76 projects (Table 6.5) in September 2009 as a temporary protection per the plaintiff's request (Yindepit, 2010). Appendix D shows the full list of the suspended projects and activities.

Table 6.5 Projects suspended as of October 5, 2009

Industry	Number of projects	Investment (Mil.THB)	Income (Mil.THB)	Number of Employees
Petrochemical	42	181,061	193,253	2,960
Petroleum	6	59,742	33,815	8
Power	4	10,502	4,300	107
Steel	10	17,212	12,747	1,534
Logistics	8	6,595	4,027	120
Industrial Estate	4	8,485	8,997	5,020
Others	2	4,500	5,100	80
Total	**76**	**288,097**	**262,239**	**9,829**

6.3.1 The impact from the suspension

The suspension directly caused a considerable impact on the economy and society. The investment loss and income loss in MTP projects were estimated at 288,097 million THB (or 5,329.54 million GBP[2]) and 262,239 million THB per year (or 4,851.19 million GBP per year[2]) respectively. The full-time employment loss and construction employment loss were estimated at 9,829 and 100,000 person respectively (Yindepit, 2009). Another 400,000 million THB (or 7,399.65 million GBP[2]) of loss was due to multiplication of demand effects in the supply chain (Chuchottaworn, 2009). The Federation of Thai Industries stated that the ruling could affect investment trends as investors might relocate their projects elsewhere. Thus, if this impasse remained unsolved, the impact on the overall national economy could be more severe (The Nation, 2010). Additionally, it was expected that each of the suspended projects needed to pay at least THB 500,000 (or about 9,250 GBP[2]) to cover the costs of the mandatory health and environmental impact assessment, in addition to costs for advertising for public hearing and other expenses (The Nation, 2010).

6.3.2 The cooperative effort to resolve the problem

The top priority was to resolve the violation issue against the Constitution Article 67. In this regard, a 4-party committee, chaired by former Prime Minister – H.E. Anand Panyarachun was appointed. The committee consisted of representatives from the government, the industries, the communities and the accredited experts (Office of Prime Minister, 2009). The main missions of the committee were to:

- Classify project or activity that may seriously affects the communities on environment, natural resources, and health aspect.
- Study the establishment of independent organisation in terms of operational approach, organisation structure, roles and responsibility
- Finalise the guideline for health impact assessment (HIA) and public participation. This involved assigning the Ministry of Public Health to prepare the HIA requirements and the Ministry of Natural Resources and Environment to incorporate the HIA into the Environmental Act.

[2] An average exchange rate of the year 2009: 54.0566 THB per GBP (BOT, 2011).

Primarily, the committee clarified that, amongst the suspended projects, there were projects that were not contributing to the increase of pollutions, rather, there were projects that would enhance the energy efficiency and environmental impact. Consequently the Central Administrative allowed 25 projects to resume their operations.

6.4 ANOTHER INCONVENIENCE

Besides the emissions from the industrial operation, local people also encountered with pollution from the construction, transportation and the increased population. However, the most significant impact from the operation and proliferation of the industries in Map Ta Phut area was the change of communities' way of life from agricultural to industrial (Yindepit, 2009). This would not be a problem if there was no inequity between the successful industries and surrounding communities.

Rayong's economy had been growing and significantly contributed to the National economy. Its gross provincial product per capita (GPP) ranked first in 2008 (Table 6.6). Its GPP contributed to the national gross domestic product (GDP) in the range of 5-7%, higher than many major cities such as Chonburi (5%), Samut Sakhon (3-4%) and Chiang Mai (1-2%) (Figure 6.4). Unsurprisingly, the industrial sector was the main contributor to the economic growth (Table 6.7).

Table 6.6 **The 10 highest GPP per capita in 2008 (THB per year)**

Province	THB	GBP[a]
Rayong	1,011,476	16,291
Samut Sakhon	623,642	10,044
Phra Nakhon Sri Ayuthaya	548,678	8,837
Samut Prakarn	499,254	8,041
Chonburi	400,456	6,450
Chachoengsao	334,070	5,381
Bangkok Metropolis	334,053	5,380
Pathumthani	254,939	4,106
Saraburi	251,751	4,055
Phuket	222,851	3,589

[a]An average exchange of the year 2008: 62.0880 THB per GBP (BOT, 2011).

Source: NESDB, 2009.

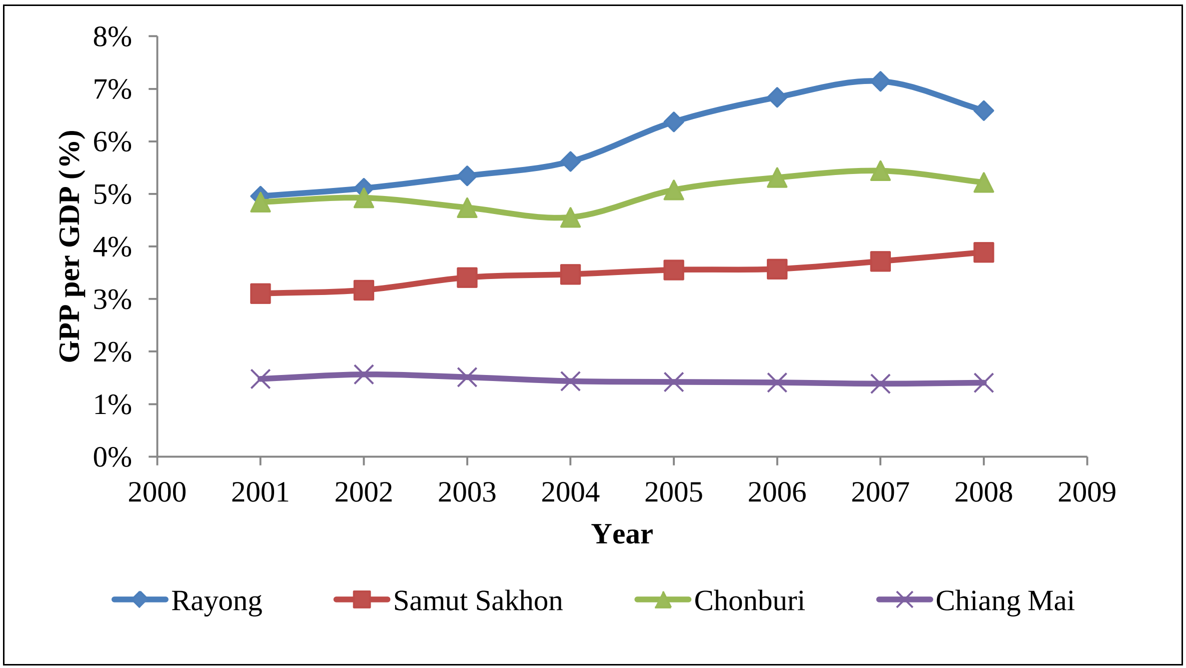


Figure 6.4 **Gross provincial product (GPP) per gross domestic product (GDP) of selected provinces in 2001 – 2008**

<u>Table 6.7</u> Contribution of each sector to Rayong's gross provincial product (GPP) in 2008

Sector	Contribution to GPP
Agriculture	
Agriculture, Hunting and Forestry	2.64%
Fishing	0.52%
Non-Agriculture	
Mining and Quarrying	37.89%
Manufacturing	42.39%
Electricity, Gas and Water Supply	7.07%
Construction	0.76%
Wholesale and Retail Trade; Repair of Motor Vehicles, Motorcycles and Personal and Household Goods	2.44%
Hotels and Restaurants	0.48%
Transport, Storage and Communications	2.16%
Financial Intermediation	0.53%
Real Estate, Renting and Business Activities	0.44%
Public Administration and Defence; Compulsory Social Security	1.78%
Education	0.48%
Health and Social Work	0.26%
Other Health-care, Social and Personal Services Activities	0.14%
Private Households with Employed Persons	0.01%

Source: NESDB, 2009.

By law, the national development budget was allocated on a per capita basis. Rayong's registered population was less than 600,000 or less than 1% of the national population (Table 6.8). But the actual population needed to include the non-residential population. Consequently, Rayong did not receive a development budget in proportion to the province's industrial contribution to the nation and this resulted in inadequate infrastructure, public utilities and health-care to match. This development mismatch created a large gap between the industrial development and a local health-care development which resulted in a public outcry for a better standard of living (Chuchottaworn, 2009).

Table 6.8 Population statistic from 2004 - 2008

Item	2004	2005	2006	2007	2008
Rayong population	562,000	569,000	577,000	584,000	591,000
Thailand population	64,531,000	65,099,000	65,574,000	66,041,000	66,482,000
Rayong population comparing to national population	0.87%	0.87%	0.88%	0.88%	0.89%

6.5 LESSON LEARNT AND A DRIVE FOR FUTURE SUSTAINABLE SUCCESS

The problems at Map Ta Phut and its vicinities were the good examples of the rapid and successful industrial development with unexpected consequence. As the industries were successful, the government became complacent and allowed all petrochemical projects to be concentrated in just one location during the past few decades for the benefits of economies of scale and industrial efficiency. However, it became a drawback when there were irresponsible operators and no one was called to account for the pollution problems particularly the excess of carrying capacity and communities' health problems (Chuchottaworn, 2009). Unavailability of corresponding social plan also exacerbated the situation.

In order to prevent the similar problems in the future, the author considered that all relevant sectors should collaborate to ensure that the industries, particularly large-scale industrial complexes, are developed in the most efficient way while including environmental and social responsibility. In other words, the economic, environmental and social aspect must be well balanced. There are 3 key success factors as follows.

6.5.1 Regulatory practicality and enforcement

6.5.1.1 The practicability of the laws and regulations

Highly stringent standards would unquestionably be beneficial to environmental protection. But if only certain companies, mostly large or international ones, were able to comply with them, these goodwill standards would turn into a threat to the economy as entrepreneurs with limited resources, typically domestic or small and medium ones, would indirectly forced out of the business. Thus, the highly stringent laws and regulations should be well assessed to ensure necessity and practicality before being proclaimed to avoid any unintentional negative effect on economy and environment. The study of international practices and discussion with the industrial sectors prior to the proclamation were recommended. Moreover, the incompleteness of proclaimed laws impeded the industries from the attempt to comply with laws and regulations. Therefore, all concerned regulatory substances should be supplied for the operators to follow straightforwardly.

6.5.1.2 Enforcement effectiveness

The violation of laws and regulations was the result of ineffective enforcement of government agencies and the ignorance of good governance practice of some operators. Thus, the government must put efforts and resources to ensure effective enforcement so that all operators are comply with the applicable laws and regulations (Yindepit, 2009).

6.5.2 Industrial performance enhancement

The author suggested that individual companies should attempt to reduce their pollutions through enhancing their energy efficiency, adopting green technology, and fostering innovation research, development and deployment. This would not only be beneficial to the environmental performance, but also the company’s financial effectiveness as more efficiency meant less natural resource consumption, more valued products and less pollutions leading to less feedstock cost, more income, less pollution treatment cost and more profit. Besides the environmental aspect, the company should conduct health risk assessment both short term and long term and find appropriate mitigation measures. In addition, the industries could establish the partnership to help each other with emerging issues and raise the overall industrial standard via best practice and lesson learnt sharing. More importantly, large companies with green technology expertise could play a major role in assisting smaller firms with limited resources and capability to implement, develop or upgrade their environmental management. However, level of assistance was subjected to agreement between firms as there may be certain associated issues such as confidentiality and competitiveness.

6.5.3 Social acceptance

It was undeniable that social acceptance has became one of the key factors for industrial success. Entrepreneurs must, therefore, take social aspects into consideration from the beginning of their projects. In establishing new industrial complexes or making any changes to the existing ones, the potential impact from such establishment or changes on the nearby communities both environmental and social should be assessed. The proper mitigation and management measures should be well designed and re-evaluated to suit the dynamic circumstances. It was important that the communities acknowledged these attempts by the industries and had a correct understanding of industrial operations. Moreover, the communities deserved the proper benefits from having industrial sites in their neighbourhood, which could be in the form of appropriate allocated budget and/or direct contribution from the industries. Accordingly, there were 3 factors contributing to the good social acceptance:

6.5.3.1 Communication and the role of communities

Effective and regular communication between the industries and local people would enhance a better understanding of industrial operations. Essential matters to be habitually communicated were industrial environmental data with potential risks and the pollution and risk mitigation measures. Irregular circumstances such as incidents or abnormal flare from processes should be rapidly explained. All information must be based on scientific fact and presented in a format that was easy to understand. In addition, the companies should allow villagers and people who work for non-governmental organisations to witness their processes in order to boost confidence among the public that the industrial processes were friendly to the environment and would not affect their livelihood. Furthermore, the importance of balancing the economy and environment to bring about good quality of life should be clearly communicated to all concerned stakeholders for better understanding and acceptance (Yindepit, 2009).

The community should also be able to participate in the planning process of resource utilisation and environmental management and in the industrial environmental management verification process. Industrial environmental database developed by the government agencies or credible environmental third party is primary tool that would assist in the verification of industrial performance.

6.5.3.2 Budget allocation

The governmental budget allocation should be based on the actual population, not just the registered one, so that the actual communities' essential needs could be properly satisfied. The budget could be spent on developing basic infrastructure and public utilities, educational standards, health-care facilities and central waste treatment.

6.5.3.3 Social management and contribution of the industry

The entrepreneur should incorporate the corporate social responsibility (CSR) programme into their management plan. They might adopt ISO 26000, which provides guidance on social responsibility. In addition, the industries might directly contribute back to communities in form of comprehensive co-development projects such as education programmes, reforestation, and underwriting community development projects (Chuchottaworn, 2009). A policy of employing qualified local people was another approach favourable to the communities.

6.6 THE CONTRIBUTION OF THIS STUDY TO THE SOLUTION

Although this study focuses on the low carbon production whereas the actual environmental issues in the case study involved other pollutants and respective health aspect, the idea from this study could be applied as follows:

- It is necessary to have the transparent emissions report that allows public access such as the emissions database to give the actual data and prevent future misunderstanding, which may lead to a conflict. It is also beneficial to policy makers to issue sound and practical laws and regulations.
- The entrepreneurs need to enhance their operational efficiency and seek cleaner technology. The attempt to reduce pollutants other than carbon dioxide such as VOCs could also help reduce total carbon emissions. It is expected that enhancing efficiency and using cleaner technology would improve environmental performance, enhance the

public acceptance and be beneficial to the corporate finance as more profits could be obtained via the increase of productivity and the decrease in treatment costs.

- The low carbon technology should still be fostered as it could minimise other important environmental issues such as global warming, which means there would be fewer issues to be concerned.

6.7 CONCLUSION

The case study discussed in this chapter emphasised the reasons why the emissions mitigation and proper environmental management should be achieved. It also addressed another important aspect that was social responsibility, which required attention to the extent that the environmental does.

In order to create sustainable way of industrial development for the benefits of the overall economy, all concerned parties must collaborate to ensure a balance of economy, environment and social aspect. First, the government must ensure both the practicability of laws and regulations; and an effectiveness of enforcement. Second, the industry must ensure they operate in the responsible manner both environmentally and socially. On the environmental aspect, the industries could improve their performance through energy efficiency enhancement, renewable energy consumption, clean or low carbon technology adoption, and innovation development. On the social aspect, the industries should incorporate the corporate social responsibility (CSR) programme into their management plan. They should also conduct health risk assessment to evaluate the risk from their industrial operations and find mitigation approaches. Third, nearby communities must not be overlooked. Proper contribution to them should well managed through appropriate governmental budget allocation and industrial direct contribution e.g. co-development programmes and employment of qualified local people. Fourth, the industries should have constant and effective communication with communities to enhance better understanding on industrial operations. In addition, there should be an industrial environmental database for public access. The database could assist in identifying major sources of problematic pollutions and could provide useful information for policy making.

Finally, in order to ensure the sustainability at all levels, every person should change their mindsets that the industries were the only party responsible for the environmental pollution. This was because, as a matter of fact, every person created pollution and depleted resources in his/her daily life. Thus, it was every person's responsibility to change his/her behaviour towards more environmentally friendly actions. Basic approaches for every person to use in daily activities are energy conservation and the reduce, reuse, and recycle (3Rs) scheme. With every person contribution, the country could move towards the greener society easily.

CHAPTER 7

CONCLUSION

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CONCLUSION

7.1 REVIEW OF AIM OF STUDY

This study completed a range of tasks in order to develop guidelines for carbon emission management for the petrochemical industries in Thailand, the tasks were:

- Develop carbon budget of the petrochemical industries in Thailand.
- Evaluate carbon emission status of Thai petrochemical industries and compare it with respective chemical industries of other countries and other Thai industries.
- Assess possibilities of carbon emissions reduction.
- Identify areas for carbon emissions mitigation.
- Consider a real case study and to indicate lessons learnt from that case study.

7.2 MAJOR FINDINGS

7.2.1 Carbon budget of Thai petrochemical industries

This study employed data from environmental impact assessment (EIA) reports, which the companies submitted to the government agency. Thus, the data was considered acceptable to both the individual company and the Thai government. The data of 52 products was collected covering upstream, intermediate and downstream petrochemical industries, and plastics and other derivatives industries in Thailand. However, because it was not mandatory for industries to report emissions of carbon dioxide (CO_2) or other greenhouse gases (GHG), emissions estimates were often found missing in many cases. In this regard, CO_2 and GHG emissions were calculated from relevant data such as energy consumption. This entailed uncertainty in the developed carbon budget.

Total carbon budget of Thai petrochemical industries for the year 2008 was 11 Mtonnes CO_2eq (±10%) or 0.63 ktonnes CO_2eq per ktonne of production (±10%). Upstream petrochemical industries were the main emission contributor (53%) followed by intermediate and downstream petrochemical industries, which had equal emission share of 23%. There were 2 factors that controlled emission level and lead to increased emissions: production capacity and emissions intensity. In view of the need for sustainable development, the country should preferably manage emission intensity as it would not be good to the national economy to decrease emissions through reducing industrial production.

In addition, the uncertainty analysis suggested that data incompleteness of p-xylene, mixed C4, polystyrene and purified terephthalic acid (PTA) was the main source of error in the total carbon budget. Acquiring higher quality data of these products would improve accuracy and precision of the total carbon budget.

7.2.2 Possibility of carbon emissions reduction in Thai petrochemical industries

The study found that carbon emissions of Thai petrochemical industries could be reduced by 25-61% through adapting current best practice. This meant the industries did not need technology breakthrough but good investments in existing effective technologies, engineering and environmental management. However, accessing such technologies, engineering and environmental management might need joint ventures with companies that possessed technology capacity.

7.2.3 Necessity and areas for carbon emissions mitigation in petrochemical industries

Although there was currently no carbon emissions reduction obligation for Thai industry and carbon emission intensity of Thai petrochemical industries was low in comparison to respective chemical industries of other countries and to other Thai industries, the petrochemical industries still should advance their environmental performance and technologies to prepare themselves for the potential of future reduction obligations. In addition, advancing environmental performance would lead to less environmental management expenditure, better green competitiveness, sustainable development of the industries, and a better living standard for the country.

In general, carbon emissions mitigation could be achieved in 2 ways: reduction of emission generation or emission intensity, and reduction of emission release. The first approach involved a shift to less- or zero- carbon intensive feedstock, an efficiency enhancement and a development of cleaner technologies. The second approach focused on carbon capture and storage (CCS) retrofitting into current production processes.

The study suggested that carbon emissions mitigation in the petrochemical industries should be started with enhancing energy efficiency at onsite utility plants. Otherwise, the industries should seek for utility supplies with higher energy efficiency. Other mitigation areas also need to be started in parallel; research and development sector would play an important role accordingly.

7.2.4 Supports from other sectors

Besides an attempt of the petrochemical industries, collaboration from all relevant sectors was important to the success of emissions reduction at both the individual plant scale and national scale. Each sector could make its contribution in term of emissions cut or other forms of support. However, it was not necessary to mitigate emissions in every sector equally. Instead, it should be prioritised based on urgency, current and projected emissions share, along with the ease and likelihood of success.

The government could issue various policies and measure to stimulate a low carbon economy in the most cost effective manner. However, they have to ensure that such policies and measures would not lead to any other issues such as carbon leakage as a result of carbon cap policy or an increase of food price as a result of biomass promotion policy. In addition, as the petrochemical industries highly consumed carbon intensive resources, they were likely to be sensitive to tentative policies and measures e.g. carbon pricing. And the prolonged capital infrastructure investment was already in place. Thus, a clear and early signal from the government was critical to them.

Nevertheless, one should bear in mind that no single technology could handle the task of emissions mitigation alone. Neither policy makers could predict in detail the cheapest ways to achieve emissions reductions. The best solution might be a combination of a good industrial practice, an effective technologies and efficient policies and measures.

7.2.5 Others

Besides environmental aspect, the petrochemical industries should pay attention on social responsibility to foster a good understanding and acceptance of nearby communities towards industrial operations. This is beneficial to the existing industrial activities and future industrial expansion.

7.3 IMPLICAIONS

7.3.1 The use of carbon budget and its development methodology

The carbon budget of Thai petrochemical industries could be used by policy makers and industrial operators in the following ways.

- *By policy makers*: a carbon budget is a good source of information for policy makers to understand a real situation and possible trend in industrial emissions. Accordingly, policy makers would be able to issue sound and practical laws and regulations. In a larger scale, a national carbon budget with analysis of each emission sector would be beneficial in future global negotiations.
- *By petrochemical operators*: A petrochemical operator could use a carbon budget as a benchmark against the overall petrochemical industries or against respective petrochemical phase. This would assist them with competitiveness analysis and encourage them to improve their industrial operation towards higher efficiency and greater cost effectiveness.

- *By other industries*: Entrepreneurs in other industries that consume petrochemical products as their feedstock could employ emissions intensity values from the petrochemical industries to calculate their carbon emission loading. It would also assist entrepreneurs in selecting right suppliers.

Moreover, the methodology of carbon budget development in this study could also be applied to develop a budget of carbon emissions or other emissions in other industries.

7.3.2 Research and development opportunities

The possibility of emissions reductions in the petrochemical industries provides opportunities in the research and development (R&D) sector. This includes R&D in the petrochemical industries themselves, R&D in the academic sector, R&D in the government agency and R&D in other industries.

Areas to be focused could be technical aspects of industrial emissions mitigation such as development of low carbon intensive feedstock; efficiency enhancement; cleaner technology development and CCS; or they could be non-technical related; for example, a development of policies and measure that would motivate low carbon economy and suitable for Thai industries.

7.3.3 Corporate management and partnership development

An entrepreneur might consider incorporating carbon emissions management and social responsibility programme into their corporate strategies so that attention of staff at all levels could be assured and respective activities could be well performed. Moreover, as suggested in section 7.2.2, an entrepreneur might consider developing partnership for higher efficient operational practices.

7.4 SUGGESTIONS FOR FURTHER WORK

Suggested further works are:

7.4.1 Improvement of presented carbon budget:

The carbon budget of the petrochemical industries could be improved through acquiring higher quality data of the following items:

- Emissions of carbon dioxide and other greenhouse gases from the production of p-xylene, mix C4, polystyrene and PTA
- Specific emission factor of each fuel gas consumed by each petrochemical plant
- Emissions of each petrochemical plant categorised as industrial process emissions and as energy sector emissions
- Fuel consumption of each petrochemical plant categorised as fuel for industrial process and fuel for energy sector.
- Boiler efficiency of each plant

Additionally, the following products should be included in the next carbon budget development due to their considerable production.

- Intermediate petrochemical industry: ethylene dichloride, vinyl chloride, caprolactum, ethylene benzene
- Downstream petrochemical industry: polyvinyl chloride

7.4.2 Development of carbon budget of other industries in the supply chain:

Carbon budget of other industries in the supply chain e.g. petroleum industries should be developed. This would be useful for producers in the entire supply chain in term of more specific data supply especially those who exporting finished products to countries that require carbon emission data.

7.4.3 Study of emissions mitigation approaches:

This study presented broad areas of carbon emissions mitigation. It is recommended that further study should be conducted to assist emissions mitigation in the petrochemical industrial operations. The recommended topics are energy efficiency enhancement of on-site utility generation, development of low carbon feedstock, development of clean technology, and feasibility on carbon capture and storage (CCS) in Thailand.

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APPENDICES

APPENDIX A

GENERAL UNIT CONVERSION FACTOR

A.1 Energy

1	Megajoule [MJ]	=	1.00×10^{6}	Joule [J]
		=	2.78×10^{-1}	kilowatt-hour [kWh]
		=	9.48×10^{2}	British Thermal Unit [BTU]
		=	2.38×10^{5}	Calorie [Cal]

A.2 Power

1	kilowatt [kW]	=	3.60×10^{6}	Joule per hour [J/h]

A.3 Weight and mass

1	tonne	=	1.00×10^{9}	milligramme [mg]
		=	1.00×10^{6}	gramme [g]
		=	1.00×10^{3}	kilogramme [kg]
		=	2.20×10^{3}	pound [lb]

A.4 Volume

1	cubic metre [m^3]	=	1.00×10^{6}	millilitre [ml]
		=	1.00×10^{3}	litre [l]
		=	1.00×10^{6}	cubic centimetre [cm^3]
		=	35.315	cubic foot [ft^3]
		=	6.11	barrel (UK) [bbl (UK)]

APPENDIX B

CURRENCY EXCHANGE

Table B.1 Exchange rate (Thai Baht per British Pound Sterling)

Year	Average Exchange Rate
2002	64.9388
2003	68.1691
2004	74.1328
2005	73.5385
2006	70.1937
2007	69.5528
2008	62.0880
2009	54.0566

Source: Bank of Thailand (BOT, 2011)

APPENDIX C

ENVIRONMENTAL LAWS AND REGULATIONS PERTAINING TO PETROCHEMICAL INDUSTRIES IN THAILAND

Table C.1 **Environmental laws and regulations pertaining to petrochemical industries in Thailand**

Laws and Regulations	Issued
Overall environmental management	
1. Enhancement and Conservation of National Environmental Quality Act B.E. 2518	1975
2. Ministry of Industry's Thirteenth Announcement (B.E. 2525) regarding responsibility of individual obtaining permission to operate industrial business	29 June 1982
3. Ministry of Industry's Thirteenth Announcement (B.E. 2525) regarding responsibility of individual obtaining permission to operate industrial business	28 June 1985
4. Department of Industrial Works' Regulation regarding registration of controller and operator of pollution prevention system B.E. 2528	16 December 1985
5. Department of Industrial Works' Regulation regarding the production of pollutant analysis report B.E. 2528	16 December 1985
6. Enhancement and Conservation of National Environmental Quality Act B.E. 2535	1992
7. Ministry of Industry's regarding classification and size of factory, measures to control the discharge of waste, pollutant, or any substance that has the environmental impact, and qualification of controller and operator of pollution prevention system B.E. 2545	7 May 2002
Air emissions	
8. Ministry of Industry's Announcement regarding regulating factory to install equipment or special device to automatically monitor air emissions from stacks B.E. 2544	22 January 2002
9. Ministry of Industry's Announcement regarding specifying amount of air pollutants from incinerator burning filth and industrial hazardous wastes B.E. 2545	30 October 2002

<u>Table C.1</u> Environmental laws and regulations pertaining to petrochemical industries in Thailand (cont.)

Laws and Regulations	Issued
Air emissions (cont.)	
10. Ministry of Industry's Announcement regarding specifying amount of sulphur dioxide emissions from factory using fuel oil as combustion fuel	27 May 2004
11. Ministry of Industry's Announcement regarding amount of air pollutant emissions from cement plant B.E. 2004	25 June 2004
12. Ministry of Industry's Announcement regarding amount of air pollutant emissions from power generation, distribution or supplier plant B.E. 2004	7 October 2004
13. Ministry of Industry's Announcement regarding amount of air pollutant emissions from factory	9 May 2005
14. Ministry of Industry's Announcement regarding amount of air pollutant emissions from factory using used oil, of which the quality was fine-tuned, and synthetic fuel as fuel in industrial burner B.E.2548	14 July 2005
Wastewater	
15. Ministry of Industry's Second Announcement (B.E. 2539) regarding specifying quality of industrial wastewater	27 June 1996
16. Department of Industrial Works' Second Announcement regarding changing of quality of industrial wastewater stipulated in the Ministry of Industry's Second Announcement (B.E. 2539) regarding specifying quality of industrial wastewater	4 September 1997
17. Ministry of Industry's Announcement regarding regulating factory that requires wastewater treatment system to install equipment or special device B.E. 2547	14 July 2004
18. Department of Industrial Works' Announcement regarding approval criteria to regulate factory that requires wastewater treatment system to install equipment or special device B.E. 2547	16 February 2005
19. Ministry of Industry's Second Announcement regarding regulating factory that requires wastewater treatment system to install equipment or special device B.E. 2548	8 March 2005

Table C.1 Environmental laws and regulations pertaining to petrochemical industries in Thailand (cont.)

Laws and Regulations	Issued
Solid waste	
20. Ministry of Industry’s Announcement regarding solid waste manifest system B.E. 2547	31 January 2005
21. Ministry of Industry’s Announcement regarding disposal of filth and waste B.E. 2548	25 January 2006
22. Department of Industrial Works' Announcement regarding criteria for delegating hazardous waste collector and manifest according to the Ministry of Industry’s Announcement regarding disposal of filth and waste B.E. 2548	17 August 2006

APPENDIX D

LIST OF 76 PROJECTS AND ACTIVITIES SUSPENDED BY THE CENTRAL ADMINISTRATIVE COURT DUE TO THE VIOLATION OF ARTICLE 67 UNDER THE CONSTITUTION OF THAILAND

Table D.1 List of 76 projects and activities suspended by the Central Administrative Court due to the violation of Article 67 under the Constitution of Thailand

Project Title	Owner
1. The expansion of high density plastics production At Map Ta Phut Industrial Estate, Rayong	Bangkok Polyethylene Public Company Limited
2. The expansion of skinpassed steel plate production At SLP Industrial Park, Rayong	G Steel Public Company Limited
3. The production of ethanolamine At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Thai Ethanolamine Company Limited
4. The expansion of epoxy resin production At Map Ta Phut Industrial Estate, Rayong	Aditya Birla Chemicals (Thailand) Company Limited
5. The production of profile steel and hot rolled steel At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Siam Yamato Steel Company Limited
6. The expansion of coated steel production At Map Ta Phut Industrial Estate, Rayong	Siam Tinplate Company Limited
7. The gas separation plant, unit 6 At Map ta Phut District, Rayong	PTT Public Company Limiteed
8. The expansion of cold-rolled stainless steel production Rayong Industrial Park, Rayong	Thainox Stainless Public Company Limited
9. The expansion of bolts and round steel bars production At Nikom Pattana District, Rayong	Tycoons Worldwide Group (Thailand) Public Company Limited
10. The expansion of ethylene oxide and ethylene glycol production At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	TOC Glycol Company Limited

Table D.1 **List of 76 projects and activities suspended by the Central Administrative Court due to the violation of Article 67 under the Constitution of Thailand (cont.)**

Project Title	Owner
11. The production of acrylonitrile and methylmethacrylate At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	PTT Asahi Chemical Company Limited
12. The production of bisphenol A At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	PTT Phenol Company Limited
13. The expansion of polycarbonate production, plant 2 At Padaeng Industrial Estate, Rayong	Thai Polycarbonate Company Limited
14. The production of methylmethacrylate, plant 2 At Map Ta Phut Industrial Estate, Rayong	Thai Polycarbonate Company Limited
15. The expansion of polyethylene production At Map Ta Phut Industrial Estate, Rayong	Siam Polyethylene Company Limited
16. Clean fuel and product quality improvement At Map Ta Phut Industrial Estate, Rayong	Rayong Refinery Public Company Limited
17. The expansion fo polyvinylchloride production, line 8 and 9 At Map Ta Phut Industrial Estate, Rayong	Thai Plastic and Chemicals Public Company Limited
18. The expansion of vinylchloride monomer production, plant 1 and 2 At Map Ta Phut Industrial Estate, Rayong	Thai Plastic and Chemicals Public Company Limited
19. The productionof propylene oxide and propylene glycol At Asia Industrial Estate, Rayong	MTP HPPO Manufacturing Company Limited
20. The expansion of polyethylene production (50,000 tonne per year) At Map Ta Phut Industrial Estate, Rayong	PTT Chemicals Public Company Limited
21. The expansion of Hemaraj Eastern Industrial Estate (Map Ta Phut) At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Industrial Estate Authority of Thailand and Eastern Industrial Estate Company Limited

Table D.1 **List of 76 projects and activities suspended by the Central Administrative Court due to the violation of Article 67 under the Constitution of Thailand (cont.)**

Project Title	Owner
22. The improvement of gas recovery system of polypropylene production plant At Map Ta Phut Industrial Estate, Rayong	HMC Polymers Company Limited
23. Amendment to the phenol production project At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	PTT Phenol Company Limited
24. Amendment to the epichlorohydrin (ECH) pilot plant project At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Aditya Birla Chemicals (Thailand) Company Limited
25. The production of acrylonitrile and methylmethacrylate At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	PTT Asahi Chemical Company Limited
26. The production of polyethylene At Asia Industrial Estate, Rayong	Siam Polyethylene Company Limited
27. The expansion of bisphenol A production (280,000 tonne per year) At Map Ta Phut Industrial Estate, Rayong	Bayer Thai Company Limited
28. The expasion of Hemaraj Eastern Seaboard At Muang District, Rayong	Industrial Estate Authority of Thailand and Eastern Seaboard Industrial Estate Company Limited
29. The expansion of chloalkaline production and the improvement of vinyl production At Map Ta Phut Industrial Estate, Rayong	Vinylthai Public Company Limited
30. The expansion of polyethylene production (the installation of compound production unit) At Map Ta Phut Industrial Estate, Rayong	PTT Chemical Public Company Limited
31. The production of bisphenol A At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	PTT Phenol Company Limited

<u>Table D.1</u> List of 76 projects and activities suspended by the Central Administrative Court due to the violation of Article 67 under the Constitution of Thailand (cont.)

Project Title	Owner
32. The production of molten iron At Pluak daeng District, Rayong	AISCO Resources Pte Company Limited
33. The production of NBR Latex At Muang District, Rayong	Bangkok Synthetics Company Limited
34. The expansionof nylon production At IRPC Industrial District, Rayong	Ube Nylon (Thailand) Company Limited
35. Amendment to the management of PTA and CAT of PTA production project, line 3 (total capacity after expansion is 1,460,000) At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Siam Mitsui PTA Company Limited
36. The expansion of steel bars production At Nikom Pattana District, Rayong	B R P Steel Company Limited
37. Clean fuel, fuel oil vapour controlling unit installation, and expansion of biodiesel product range (project detail amendment) At Map Ta Phut Industrial Estate, Rayong	Star Petroleum Refinning Company Limited
38. The efficiency enhancement of the aromatics plant, unit 1, phase 3 At Map Ta Phut Industrial Estate, Rayong	PTT Aromatics and Refining Public Company Limited
39. Amendment to the DME removal unit and hydrocarbon scrubber installation project At Map Ta Phut Industrial Estate, Rayong	Bangkok Synthetics Company Limited
40. The expansion of formaldehyde and urea formaldehyde production At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Vanachai Chemical Industries Company Limited
41. The installation of fuel oil vapour controlling system and expansion of biodiesel product range At Map Ta Phut Industrial Estate, Rayong	PTT Aromatics and Refining Public Company Limited

<u>Table D.1</u> List of 76 projects and activities suspended by the Central Administrative Court due to the violation of Article 67 under the Constitution of Thailand (cont.)

Project Title	Owner
42. Amendment to the polypropylene oxide and propylene glycol production project At Asia Industrial Estate, Rayong	MTP HPPO Manufacturing Company Limited
43. Amendment to the polyethylene production project At Asia Industrial Estate, Rayong	Siam Synthetic Latex Company Limited
44. Amendment to the high density polyethylene resin production project (Addition of catalyst preparation and pipe compound production) At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Thai Polyethylene Company Limited
45. Amendment to the production process and air emission treatment efficiency enhancement project of purified terephthalic acid (PTA) plant At Asia Industrial Estate, Rayong	Indorama Petrochem Company Limited
46. Amendment to the improvement of olefins production plant, I-4 road (construction of additional cracker) At Map Ta Phut Industrial Estate, Rayong	PTT Chemical Public Company Limited
47. The production of acrylonitrile and methylmethacrylate At Map Ta Phut Industrial Estate, Rayong	PTT Chemical Public Company Limited
48. The production of acrylonitrile and methylmethacrylate At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	PTT Asahi Chemical Company Limited
49. Amendment to the expansion project of high density plastic production plant (BPEX) (the temporary addition of compound production unit, line 2 in the area of Bangkok Polyethylene Company Limied) At Map Ta Phut Industrial Estate, Rayong	Bangkok Polyethylene Company Limied

Table D.1 **List of 76 projects and activities suspended by the Central Administrative Court due to the violation of Article 67 under the Constitution of Thailand (cont.)**

Project Title	Owner
50. The gas separation plant, unit 6 (the efficiency enhancement of wastewater quality improvement system for recycling) At Map Ta Phut Industrial Estate, Rayong	PTT Public Company Limited
51. The expansion of polyethylene terephthalate (PET) production At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Thai PET Resin Company Limited
52. The expansion of polycarbonate production (275,000 tonne per year) At Map Ta Phut Industrial Estate, Rayong	Bayer Thai Company Limiteed
53. Efficiency improvement and enhancement of the olefins production plant At I R L Industrial Estate, Rayong	SCG Chemcials Company Limited
54. Amendment to the chloalkali and epichlorohydrin plant (under the installation of chlorine vaporizer and wet scrubber of HCL section and liquid chlorine container size change project) At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Aditya Birla Chemicals (Thailand) Company Limited
55. The production of polyethylene (addition of polypropylene product range and volatile organic compound recovery), HDPE plant 1 At Map Ta Phut Industrial Estate, Rayong	Thai Polyethylene Company Limited
56. The expansion of I R L Industrial Estate At I R L Industrial Estate, Rayong	Industrial Estate Authority of Thailand and I R L 1996 Company Limited
57. Change of area size of the cold-rolled steel, metal coated steel and galvanized steel production project At Hemaraj Eastern Industrial Estate (Map Ta Phut), Rayong	Bluescope Steel (Thailand) Company Limited

<u>Table D.1</u> List of 76 projects and activities suspended by the Central Administrative Court due to the violation of Article 67 under the Constitution of Thailand (cont.)

Project Title	Owner
58. The expansion of synthetic rubber production At Map Ta Phut Industrial Estate, Rayong	BST Elastomer Company Limited
59. The production of hydrogen gas At Asia Industrial Estate, Rayong	MTP HP JV (Thailand) Company Limited
60. The expansion of polyvinylchloride plastic powder At Map Ta Phut Industrial Estate, Rayong	Thai Plastic and Chemicals Public Company Limited
61. IPP Industrial Zone	I.P.P. (Thailand) Company Limited
62. The production of galvanised steel sheet At Hemaraj Eastern Seaboard, Rayong	(unidentified)
63. The production of galvanised steel sheet At Hemaraj Eastern Seaboard, Rayong	JFE Steel Galvanising (Thailand) Company Limited
64. Pluak Daeng Industrial Park At Pluak Daeng District, Rayong	Pluak Daeng Industrial Park Company Limited
65. Industrial waste management project	Siam Environmental Technology Company Limited
66. The expansion of the petrochemicals transfer port and raw material and product depot At Map Ta Phut Industrial Estate, Rayong	Map Ta Phut Tank Terminal Company Limited
67. Change of location and size of raw material and product storage tank At Map Ta Phut Industrial Estate, Rayong	Map Ta Phut Tank Terminal Company Limited
68. Change of port and product depot project (Addition of storage tabk and LPG/Butene-1 transferrign equipment) At Map Ta Phut District, Rayong	PTT Chemical Public Company Limited
69. Amendment to the expansion of the petrochemicals transfer port and raw material and product depot project (the construction of raw material and product storage tank (propane/butane tank)) At Map Ta Phut Industrial Estate, Rayong	Map Ta Phut Tank Terminal Company Limited

<u>Table D.1</u> **List of 76 projects and activities suspended by the Central Administrative Court due to the violation of Article 67 under the Constitution of Thailand (cont.)**

Project Title	Owner
70. The expansion of petrochemicals transfer port (port number 4) and raw material and product depot At Map Ta Phut Industrial Estate, Rayong	Map Ta Phut Tank Terminal Company Limited
71. The installation of additional loading arm at Star Refinery port At Map Ta Phut Industrial Estate, Rayong	Star Petroleum Refining port
72. Cogeneration power plant At Eastern Seaboard (Rayong), Rayong	Glow Hemraj Energy Company Limited
73. Natural gas pipeline to PTT Utility Company Limited, Aromatics (Thailand) Company Limited, and Map Ta Phut Olefins Company Limited	Aromatics (Thailand) Company Limited
74. Power plant for industry At Amata City Industrial Estate (Rayong), Rayong	Amata Stream Supply Company Limited
75. Petrochemicals pipeline At Map Ta Phut Industrial Estate, Rayong	Stylene Monomer Company Limited, Siam Polyethylene Company Limited, and Rayong Olefins Company Limited
76. Second central utilities At Map Ta Phut District, Rayong	PTT Utility Company Limited